23-2

Library
for Science and
Technology.

8936

TRANSACTIONS *of the*

ILLUMINATING ENGINEERING SOCIETY

Founded in London in 1909 and incorporated in 1930

Volume 23 Number 2 — 1958

Officers of the Society, Session 1957-1958

President E. B. SAWYER (FELLOW)

Vice-Presidents F. X. ALGAR B.SC. (FELLOW) N. BOYDELL M.I.E.E. A.M.I.MECH.E.

R. G. HOPKINSON B.SC. (ENG.) PH.D. M.I.E.E. (FELLOW)

J. S. MCCULLOCH ASSOC.I.E.E. (FELLOW) C. C. SMITH M.I.E.E. (FELLOW)

Honorary Secretary J. G. HOLMES A.R.C.S. B.SC. (FELLOW)

Honorary Treasurer W. ROBINSON B.SC. A.M.I.E.E. (FELLOW)

Honorary Editor of Transactions H. HEWITT A.M.I.E.E. (FELLOW)

Secretary G. F. COLE

TRANSACTIONS *of the* ILLUMINATING ENGINEERING SOCIETY

Volume 23 Number 2 1958

Contents

63 **Sir John Herbert Parsons**

65 **Lighting of Aircraft Control Panels**
J. W. Strange PH.D. A.R.C.S. (FELLOW) *and B. Stevens* (MEMBER)

84 **Ambient Temperature Effects in the Photometry of Fluorescent Lamps**
W. R. Blevin M.SC.

87 **Lighting and Safety in Building Operations and Works of Engineering Construction**
J. Gordon Scott

101 **Lighting Design—The Next Step**
Interim Report of the Lighting Design Data Panel of the Technical Committee

113 **Design of the Visual Field as a Routine Method**
J. M. Waldram B.SC. (FELLOW)

124 **Supplementary Note**
W. Robinson B.SC. A.M.I.E.E. (FELLOW)

125 **Additions to the list of members**

Sir John Herbert Parsons

(1868—1957)

President 1921—1923

A biographical sketch and a tribute

Fifty years ago Leon Gaster was seeking to interest a number of people in his project to found a Society for the purpose of bringing together all who had in common a particular interest in lighting. Among those who might be expected to have such an interest were ophthalmologists, because seeing is manifestly dependent upon lighting. At that time Dr. J. H. Parsons was already an ophthalmologist of high repute and Gaster was fortunate in finding him ready to take an active interest in the new project. Parsons was, in fact, invited to be the first president of the new Society but declined because he thought a physicist or an engineer would be a more appropriate choice. Instead he became the first Chairman and thus, so to speak, the father of the Council. It was he, therefore, who presided over the governing body of the Society in those critical post-natal days. Forty-eight years—almost to the day—after he first took office his life came to its close in his 90th year on 7th October, 1957.

He was born in Bristol on 3rd September, 1868, and began his medical education at the University College of Bristol and the Bristol Royal Infirmary. But it was from St. Bartholomew's Hospital in London that he qualified in medicine with the degree of M.B. at the age of 24, having, two years previously, obtained a B.Sc., Lond., degree with honours in physiology.

In 1900 he obtained his Fellowship of the Royal College of Surgeons and then specialised in ophthalmology. Four years later he was elected to the surgical staff of Moorfields Eye Hospital and he also became ophthalmic surgeon to University College Hospital in London. At the same time he had a busy private consultant practice. Yet he found time not only to serve on numerous important committees, and to take office in his own professional societies as well as in the I.E.S., but also to write a number of erudite and important books and very numerous contributions to ophthalmic publications. He became, as Lord Adrian said of him on his 80th birthday, " the adviser of governments, and the expert whose opinion is indispensable in all the varied problems where human vision is concerned."

Before the founding of the I.E.S., Parsons had published the earlier of his books : of these, the most notable were his text-book of " Diseases of the Eye "—which has been through many editions since 1907 and is still a standard work—and his masterly " Pathology of the Eye " which appeared in four volumes during the period 1904-1908.

Early in the first session of the I.E.S.—actually in January, 1910—the first paper was presented and Parsons was its author. He chose as his subject " Glare, its Causes and Effects." This was afterwards published in Vol. 3 of *The Illuminating Engineer* (the forerunner of *Light and Lighting*) together with communications to the discussion received from notable scientists in a number of countries. Then, in 1913, when the Home Secretary first set up the Departmental Committee on Lighting in Factories, Parsons was appointed a member and continued to serve on this committee during all its active periods, which were spread through nearly 30 years.

His " Introduction to the Study of Colour Vision " was published by the Cambridge University Press in 1915 and it exemplified his great ability in dealing with a difficult subject and presenting a critical account of rival theories.

In the same year the Factory Lighting Committee made its first report and then went into abeyance for the remainder of the war. Parsons was then appointed consultant ophthalmologist to the Armed Forces with the rank of Colonel. Recognition of his services came in 1919 when the honour of C.B.E. was conferred on him. In that year, too, he served the I.E.S. again as chairman of the Committee on Eyestrain in Cinemas which was set up at the request of the L.C.C. and whose report, published in 1920, contained recommendations which were translated into regulations made by cinema licensing authorities which have been in force ever since.

In 1921 Parsons was elected President of the I.E.S. He was the fourth man to hold this office and he held it for two years. These were among the most momentous years of his life for it was in 1921 that his eminence as a scientist was signalised by his election to Fellowship of the Royal Society, and it was in 1922 that he received the honour of knighthood. At this time too, he was appointed Chairman of the committee set up by the Medical Research Council to inquire into the possible causes of miners' nystagmus, among which were the conditions of lighting prevailing at the coal face.

An overriding interest of Sir John's was the pursuit of knowledge about vision and also, more widely, about man's other sensory capacities and " springs of conduct." He recognised the need to make this pursuit possible by others too who had the zest and the ability for it. With this in mind, he was instrumental in getting the Medical Research Council to set up in the early 1920s a standing committee for the purpose of promoting vision research. He was chairman of this committee up to the outbreak of war in 1939. Under its auspices, a selected band of able researchers worked, and the fruits of their work were published by the Council in a series of special reports. It is noteworthy that the first of these was Lythgoe's " Illumination and Visual Capacities " and, later on, came his " classic " dealing with the relation between illumination and visual acuity. Others in the series were W. D. Wright's reports of his early work on colour vision. A parallel body set up by the Department of Scientific and Industrial Research was the Illumination Research Committee, and Parsons was also a member of this throughout its life. Here too, the outcome was a series of researches of which that of Stiles on glare is a well-known example. The two great research bodies—the M.R.C. and the D.S.I.R.—were in close concert on the subject of vision and lighting, mainly through the person of Sir John Parsons, and jointly they sponsored the investigations of Weston and Taylor, of Adams, and then the work of Weston which was subsequently utilised in the post-war I.E.S. Code. Our debt to Sir John Parsons is not for his own contributions to knowledge alone, nor only for these and his direct services to the I.E.S., but also for what he did to make possible the significant work of others. His wisdom, his powerful influence and his encouragement were of the greatest value.

Sir John's " Introduction to the Theory of Perception " was published in 1927 and this, in the opinion of one of the most eminent of his former pupils, is " the greatest book he ever wrote." It is indeed a masterpiece—an outcome of great learning, great intellectual penetration and great mastery of expression. By this time he had received the degree of D.Sc. and, later, the honorary degree of LL.D. was conferred on him by Edinburgh University. Subsequently he became president of the Royal Society of Medicine.

He gave his last address to the I.E.S. in 1943, when he was the celebrity invited to speak on the occasion of the Annual General Meeting. His last book, " The Springs of Conduct "—a neuro-psychological study—was published in 1950 when he was 82. Rather belatedly, the I.E.S. conferred the distinction of honorary membership upon him in 1954.

Men of Parsons' intellectual calibre do not suffer fools gladly and he was no exception to this rule. Uncompromisingly honest, blunt and forceful when necessary and yet kindly at heart and appreciative of wit, these were some of the qualities of the man. He spoke quietly and sometimes almost languidly ; there was no affectation in this but it tended to conceal from the unperceptive something of the true value of the speaker. He was undemonstrative but he appreciated friendship and made abiding attachments. For those who captured his interest, either by their personalities or by the merit of their work in those fields of study dearest to his heart, he entertained a kindly feeling that was sincere and lasting. In them he inspired not only the respect due to a man of his integrity and erudition but also admiration and affection. He was a great man and the I.E.S. may justly be proud that he was numbered among the presidents of the Society.

UDC 628.978

Lighting of Aircraft Control Panels

By J. W. STRANGE, Ph.D., A.R.C.Sc. *(Fellow)*,
and B. STEVENS *(Member)*

Summary

The lighting of aircraft cockpits has become increasingly important with the increasing complexity of the aircraft and the exacting demands now made upon the pilot. New methods of lighting have been developed using individual "pillar" lights and trans-illuminated panels. These methods have in part superseded the earlier methods using floodlighting with ultra-violet and mixtures of white and red light. Aircraft operators would like to carry the development still further and have built-in or "integral" lighting provided with the instruments. Some methods of achieving this are described but there are still problems to be solved before they are fully applicable. This is particularly so with panels consisting of a mixture of instruments, inscriptions, switches, knobs, etc. The application of the various methods to typical aircraft control panels is described and the basis for a lighting specification is suggested.

(1) Introduction

There were no illumination problems in early aircraft. The instruments in use were very limited. A tachometer and an oil drip feed were probably the first two instruments which a pilot had to keep under observation and as all flying was done in daylight conditions in an open cockpit there were no needs for lighting either for the pilot or for the passengers.

Since those days the control of aircraft has increased enormously in complexity and the range of conditions has also considerably widened. The flight deck of the modern aircraft may be staffed by two pilots, a navigator, and a radio operator and the aircraft has to fly and, what is more important, make landings not only in daylight but at night and often under conditions of very poor visibility. The size and landing speed of the aircraft have increased steadily over the years and today many landings are done when the pilot is only observing instruments right up to within a few seconds of touchdown, when a rapid transition has to be made from information derived mainly from instruments inside the cabin to visual observation of the outside scene.

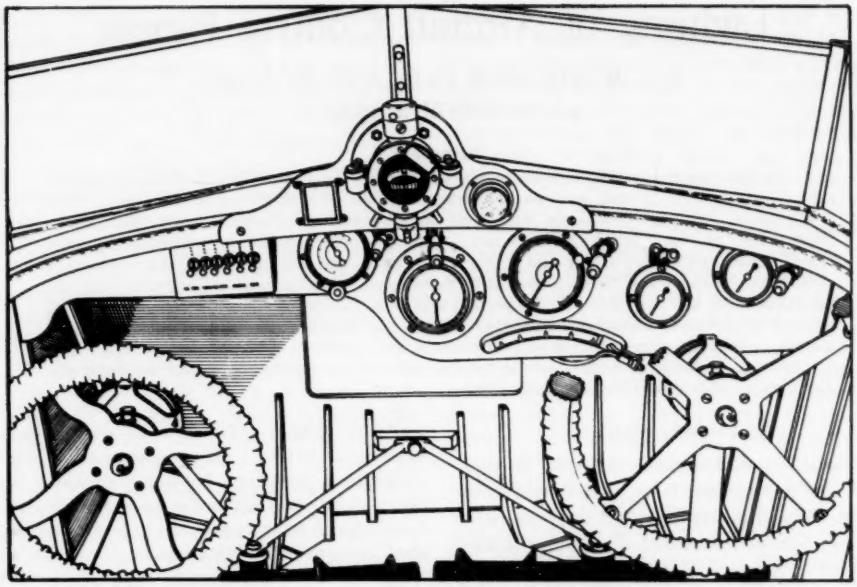
This increase in complexity of the control problem as well as the change in conditions has greatly increased the problems of satisfactory illumination. It can be said that in general the problem has been tackled by a number of expedients giving more or less satisfactory results rather than a planned approach based upon known requirements. This can be illustrated by the report prepared by the Secretariat to the C.I.E. Committee dealing with airborne lighting. In their report to the Zurich Conference, 1955, they commented that "in general all countries reporting indicate that no detailed interior lighting requirements exist. The usual specification states that the interior lighting shall be suitable for the purpose."

The last sentence must be familiar to many who have attempted to define the vague requirements put up to illuminating engineers in different fields of their activity. The exact specification follows the practice and the practice is not laid down by the specification.

This same C.I.E. Report[1] gives an interesting summary of the rather chaotic position regarding aircraft lighting. The position at that time in 1955 was little different to the one the authors found when they first approached this subject about four years ago. During the ensuing years a steadily increasing contact with the problems of the aircraft industry has enabled them to form certain conclusions regarding the different types of illumination in use or proposed, and the purpose of the present paper is to summarise the practicable methods available and also to indicate the further requirements needed to give an adequate final result. We are very aware of our limited experience but we hope that this paper and the ensuing discussion will help not only us but also the aircraft industry to clarify the requirements for good illumination. Some attempt at defining the requirements in specification form has been made in the final section.

Before going on to describe the various methods in use it is worth illustrating the changing problem within the cockpit of an aircraft. Fig. 1 shows an early instrument panel and Fig. 2 gives a cross section of the layout of the panel in relation to windshield and the pilot. Figures 3 and 4 show

The authors are with Thorn Electrical Industries Ltd. The manuscript of this paper was first received on November 13, 1957, and in revised form on December 16, 1957. The paper was presented at a meeting of the Society held in London on January 14, 1958.



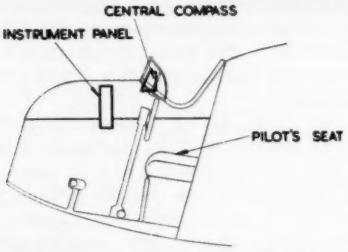


Fig. 1 (above). Early aircraft instrument panel H.P.W.10.
Fig. 2 (left). Diagram of H.P.W.10 cockpit.

the same information for a modern aircraft and Fig. 5 the layout of the cockpit for the even more difficult problem of the helicopter.

(2) Early Methods of Lighting

As soon as illumination became essential due to the development of night flying the first methods tried out were along the simple lines which might be expected. Incandescent lamps in suitable holders to provide a directional beam were mounted on brackets above or behind the pilot or underneath the coaming above the instrument board. This gave reasonable results in the simple early type of panel. The first refinement arose from the observation that the restriction of this light to the red end of the spectrum was essential to avoid problems of ghost images being observed from the corner of the eyes. This arose from the fact that parafoveal vision was more sensitive to short wavelengths than to long. This effect could be completely avoided by restricting the colour of the light to the long wavelength red-orange region. The use of red floods became the most popular method of dealing with the illumination problem with the addition of white floods for conditions when exterior visibility was not important. As the cockpit became more and more full of instruments and panels (and also crew), so the difficulty of finding places to put the lamps was increased. It was all too easy for the lamps to be hit and for the adjustment to be altered. Scattered light and reflections off glass surfaces became more noticeable and with lamps situated under coamings the operation of the inflexible inverse square law added to the difficulty. The cosine law also came into operation and gave a further increase in the range of brightness patterns.

One partial solution to the difficulties of scattered light which was presented by floodlighting was achieved by the use of ultra-violet sources, although these were also subject to limitations of the optical laws. These UV floodlights required that all instruments and legends, etc., were adequately provided with phosphorescent paint. The early sources used for this purpose were incandescent lamps with black glass filters. These were not very

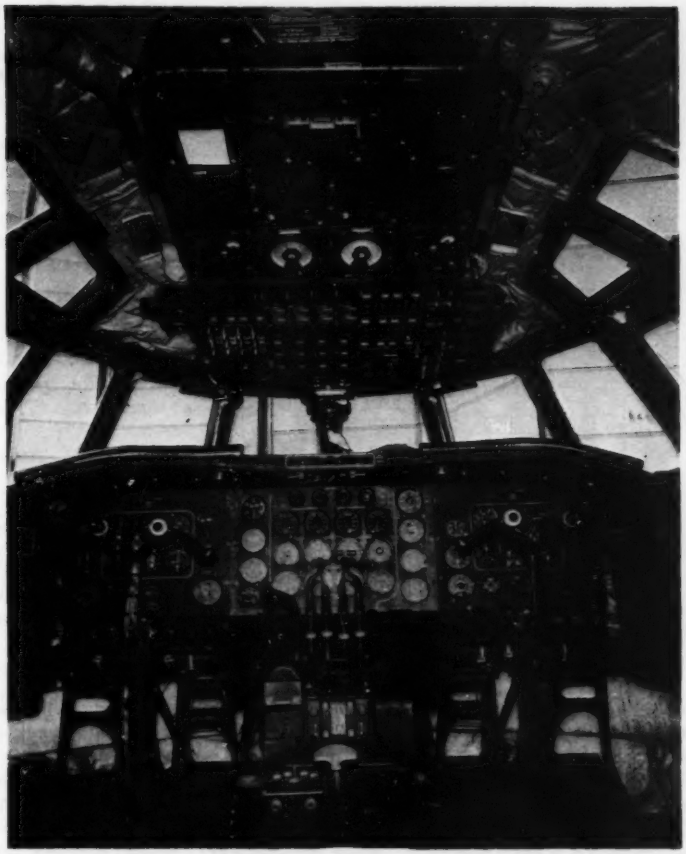


Fig. 3. Cockpit of a Britannia aircraft.

satisfactory because their output in the ultra-violet was low and their life was short. Subsequently, small ultra-violet sources using a glow discharge became avilable which could be operated from the standard 28 volts D.C. and later also a very much more efficient tubular discharge lamp which needed an A.C. supply. The general appearance of UV lighting was good and the excellent contrast pleased many users, but in certain conditions the complete absence of background lighting resulted in a floating impression. Doubts were also expressed by the medical staff on the long term effect of the scattered ultra-violet light and quite apart from the physiological reactions the fluorescence of the eyeball tended to reduce visual efficiency. The instrument makers were also not happy with the need for phosphorescent paint as it necessitated a relatively heavy needle structure and in some items of equipment, such as eyeball indicators, it presented a difficult problem in balancing the moving parts.

The position can be summarised by the following points:—

(*a*) Red or red and white floodlighting is the simplest and easiest to apply of all methods of lighting panels. It has some weight advantage but in any crowded cockpit it presents many problems and cannot give a uniform result over a panel, though over particular instruments it can be excellent.

(*b*) Ultra-violet floodlighting will give excellent results with any items suitably treated with phosphorescent paint and it gives, in particular, excellent contrast. It is also restricted by the same difficulty as floodlighting in the disposition of the sources, and consequently the uniformity of brightness is not good.

This summarises roughly the position as reported

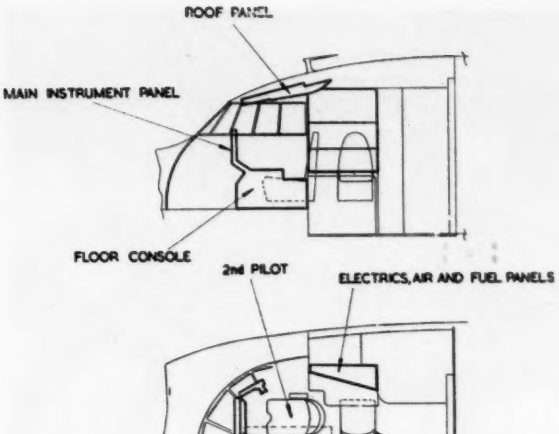


Fig. 4. Diagram of a Britannia cockpit.

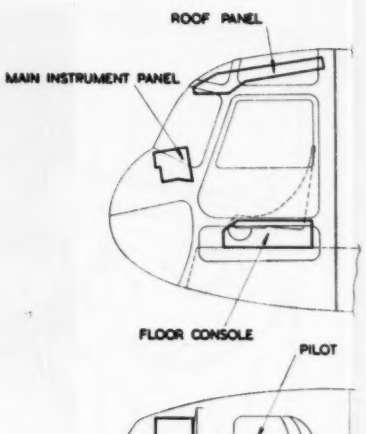


Fig. 5. Diagram of a helicopter cockpit.

to the C.I.E. in 1955, and as it was at the time when the authors first took an active interest in the subject (1953). The published material was scattered and fragmentary ([2,3]) except for certain reports of the excellent work done in the services here and in the U.S.A. which is unfortunately not available for general reference. Much thought was already being given to the subject, a start had been made on trans-illuminated panels particularly for consoles, and some developments were already in hand on individual lampholders for instruments. These different applications will now be described in more detail.

(3) New Methods

(3.1) Trans-illuminated Plastic Panels

It would be interesting to describe in detail the different steps which led to the development of the new methods, particularly that of the trans-illuminated plastic panels, but it would be difficult to be accurate and it might be tedious. The property of total internal reflection in substances such as glass, silica and plastic is very well known and it has been used for "piping" light for many years. A development of this principle in relation to plastic sheets is the basis of the process to be described. The use of this method to illuminate letters engraved in the top surface of sheets of acrylic plastic was relatively simple but many of the other problems such as getting uniformity of illumination, getting the light out from cut edges without undue scatter and in suitable directions for illuminating instruments, were more difficult. These difficulties were further accentuated in aircraft instrument panels by the very tight packing of these panels with instruments which left little room for either lampholders or even for the plastic sheet itself. Fig. 6 shows the back of such a panel and also the cobweb construction of the front plastic panel when all the necessary holes for instruments and lamps have been cut.

Some early and rather crude attempts were based upon lamps in an "integrating box" at the back of the panel. Successful development depended upon the availability of suitable small sources. The final choice lay with the midget panel lamp. The essential data for these lamps are given in Table 1. Also vital in the development was the provision of suitable holders. Both these and the lamps are illustrated in Fig. 7.

The basic construction of the panel is also given in this figure. A relatively thick sheet of acrylic

plastic is faced on the upper surface by a thin sheet of translucent white plastic. Over this is laid a second thin sheet of black opaque plastic and the whole is then bonded together to form a homogeneous panel. As will be appreciated, the transmission of light through this sheet of acrylic plastic is a combination of total internal reflection and diffusion. The amount of light transmitted in any direction from the lamp and also the amount diffused upward to the white areas of the engraved letters can be controlled by the treatment of the lower surface.

A white or a black layer can be laminated or painted on to the lower surface or, alternatively, it may be left in its original polished condition. Upon the exact treatment of this lower surface depends much of the uniformity and general appearance of the final product. The best methods are largely a matter of experience and cannot readily be put into concise terms.

The problems of control become more difficult when it is desired to direct the light which is transmitted through the panel out through the edge of the panel on to faces of adjacent instruments. The basic principles covering the behaviour of light in passing from one medium to another are well known. A light ray passing from a substance of high refractive index, e.g., glass, to one of low refractive index, e.g., air, is refracted away from the vertical towards the boundary of the two substances. In Fig. 8, we have illustrated the three possibilities for the cutting of the edge of a sheet. In (*a*) where the edge is at right angles to the general direction of the incident rays, light is refracted both up and down. In (*b*) where the angle of the cut face is down the light is refracted in an upward direction and in (*c*) where the cut edge faces up the light is refracted downwards.

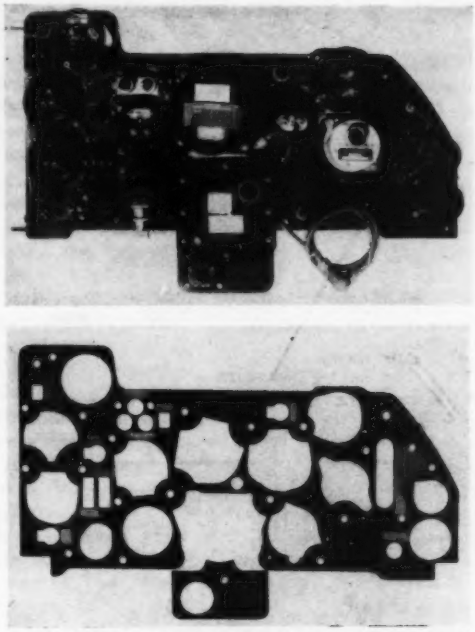


Fig. 6 (top). Back of an instrument panel; (below) transilluminated panel.

Table 1
Midget bulb data

Inter-service Reference No.	Rated volts	Filament amps	Bulb diameter mm.	Overall Length mm.	Light centre length mm.	Minimum Average Initial Lumens	Cap miniature with flange
995–9118	28	0.04	6.3 (0.249″)	14.6 (0.575″)	9.6 (0.375″)	4	S6/8
995–9122	28	0.08	6.3 (0.249″)	14.6 (0.575″)	9.6 (0.375″)	8	S6/8
995–9120	12	0.1	6.3 (0.249″)	14.6 (0.575″)	9.6 (0.375″)	4	S6/8
995–9119	6	0.1	6.3 (0.249″)	14.6 (0.575″)	9.6 (0.375″)	2	S6/8
995–9123	1.25	0.56	6.3 (0.249″)	14.6 (0.575″)	9.6 (0.375″)	0·5	S6/8

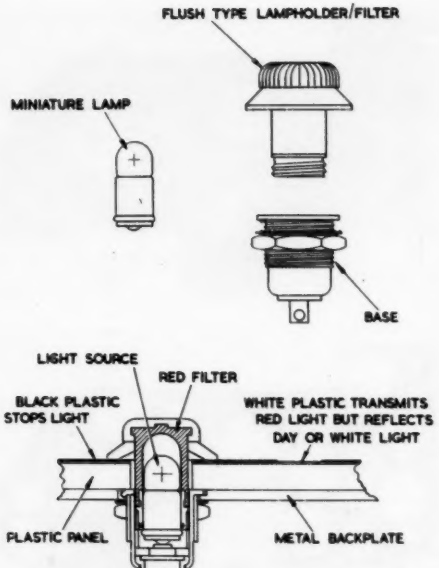


Fig. 7. Showing the basic construction of a trans-illuminated panel and a lamp and lampholder.

Although the general direction of the cut edge required is easily apparent, the exact choice of angle is not so simple. Experience shows that with a cut edge as in (*c*), light may still reach the cut edge from the back surface of the panel at such an angle that it will be refracted out in an upward direction (see Fig. 8a). Trouble may also arise from other rays which although not above the plane of the panel may be directed across the instrument to the far cut edge and there reflected in an upward direction. To avoid these two possibilities it is necessary to exercise close control over the angle of the light arriving at the cut edge. This is done in two main ways, by controlling the distance between the lamp and the cut edge and by blackening the back surface of the panel between the lamp and the edge. In this way the angle of the light rays arriving at the edge is controlled so that the refracted rays are limited to the face of the instruments alone and upward rays and rays reflected from the cut edge on the far side can be prevented.

One main problem remains and that is the reflection from the front surface of the glass of the instrument itself. At low incident angles, i.e., when nearly normal to the surface, about 4 per cent. of the light is reflected, but when the incident angle increases beyond 60 deg., a very high percentage is reflected (Fig. 9). This is a really difficult problem affecting both the trans-illuminated panels and the other methods such as the pillar lighting referred to later. Most of the trouble can be avoided by a careful layout which ensures that the reflected light is directed in harmless directions, or by the provision of suitable baffles.

Two alternative solutions are possible; either the light may be directed into the instrument through a transparent bezel so that it is introduced between the cover glass and the dial (see Fig. 10a), or the instrument cover glass may be modified so that the incident light strikes the surface at angles close to the normal. This "top-hat" type of construction is illustrated in Fig. 10(b).

It must be admitted, however, that although these are sensible suggestions, the illuminating engineer has to work with the instruments as they are, and not with improved types which he hopes to persuade the instrument manufacturers to produce. Ideas such as these may find application

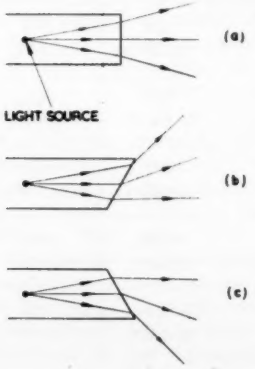


Fig. 8. Showing the distribution of light from the cut edge of a panel.

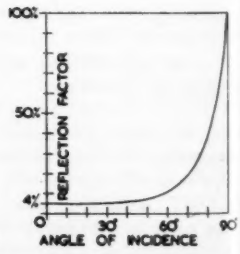


Fig. 9 (right). Showing the relationship of angle of incidence and reflected light.

in the lighting of separate units specially designed, but only in one case have we succeeded so far in modifying existing equipment; this was the Dowty "eye-ball" indicator illustrated in Fig. 10(c). The final answer will probably be to build the lighting into the instrument. This will be discussed below under the heading of "Integral Lighting."

(3.2) Pillar Lighting

The second method developed in the post-war years is the "pillar" lampholder system. The basic features of the system are illustrated in Fig. 11. As will be seen the lampholder closely resembles a pillar-box in which the light is directed through the slot on to the instrument. The main feature that makes this a practical proposition is the availability of the very small light source, which is in this case (as in the transilluminated panel) the midget panel lamp shown in Fig. 7.

The pillar lampholders are normally supported in pairs on bridge pieces designed to be fastened to the instrument flanges by their fixing bolts. In the case of the gyro compass, two pairs of lamps are needed. The majority of the instruments used in the aircraft industry fall into categories listed in Table 2. In addition to the bridge-mounted lampholders, individually mounted holders are also available which can be used for flangeless instruments, lettering and switches.

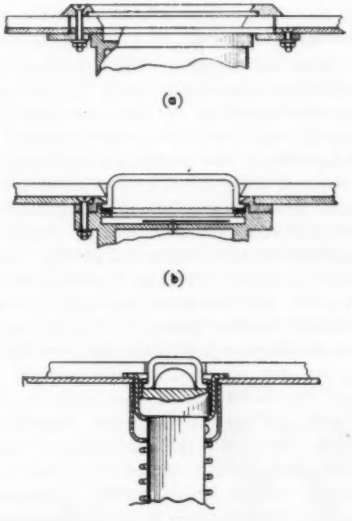


Fig. 10. (a) *Transparent bezel instrument.*
(b) *A top-hat cover glass.*
(c) *A magnetic eyeball indicator.*

The main care in the design of the equipment lies in providing a pillar lampholder which gives a light distribution through the hole so that when mounted on the bridge-piece a reasonable distribution is obtained across the face of the instrument. In order to conserve space on the panel, it is essential that the bridge-piece which carries the lampholders be as small as possible, and it must utilise the same fixing centres as the instrument itself. This equipment places a severe limitation on the siting of the lampholders themselves, a fact which is further complicated by the difference in diameter of the dials to be illuminated. Difficulties through upward reflection of light from the glass surface of the instrument, coupled with the geometry of the bridge-piece itself, impose a very limited choice of positions for the lampholder units, but these are chosen to provide the most even lighting conditions. Each of the small pillars spreads light fairly evenly within an angle of approximately 90 deg. in the plan view, while the main beam, if it can be so described, is directed downwards on to the face of the instruments at an angle of 31 deg. from the horizontal. The aperture on the pillar is so arranged that there is a certain amount of light on either side of this main beam angle, the useful content being restricted at a total included angle of 29 deg. with a fairly sharp cut-off outside this area. A pair of such pillar lamps mounted a short distance apart and aimed at the centre of the instrument provide a reasonably even illumination (see Fig. 12), which even on the larger instruments does not show a variation of more than 5 to 1 between the brightest and dimmest part of the lettering on the dial; and this is generally acceptable for white figures on a black background. Some greater degree of uniformity of illumination could be achieved by making special pillars to suit each instrument, but this would obviously present manufacturing problems which could not be accepted in the interests of economy.

To ensure replacement of the lamps in the correct position during subsequent re-lamping operations, a small locating keyway is provided in the lampholders, and a small "click" device retains the lamphousing in position. The resulting range of lighting bridges leaves no choice to the aircraft constructor except to fit a certain bridge to instruments of a given size, and some degree of non-uniformity between presentation of instruments must be accepted due to the different density of characters on the instruments. The general result, however, is quite good apart from the usual

Table 2
Types of bridge lighting units

TYPE A	Mk. G4B Gyro Compass	4 lamps	TYPE H	Large Air Ministry Case	2 lamps
TYPE B	Artificial Horizon	2 lamps	TYPE J	Instruments with 3" P.C.D. fixing	2 lamps
TYPE C	Large S.A.E. Case (4BA Screws)	2 lamps	TYPE K	Double Desynn mounted vertically	2 lamps
TYPE D	Small S.A.E. Case (4BA Screws)	2 lamps	TYPE L	Mk. G4F Compass	4 lamps
TYPE E	Horizontally mounted Double Desynn	2 lamps	TYPE M	Small S.A.E. Case (2BA Screws)	1 lamp
TYPE F	Large S.A.E. Case (2BA Screws)	2 lamps	TYPE N	Two inch flangeless Case	2 lamps
TYPE G	Small S.A.E. Case (2BA Screws)	2 lamps			

operation of the laws of illumination which impose a variation in brightness from the top to bottom of the instrument. It is found in practice, however, that this variation in the vertical direction is more acceptable than variations from left to right across the face of the dial. It is found that the small variation imposed does not affect the presentation unduly except at very low levels of brightness below 0.05 foot-lamberts.

The application of the bridge-pieces to the instruments is a straightforward operation, and only demands that suitable holes shall be drilled adjacent to the ends of the bridge to accept the leads which supply the lamps. The lamps are individually wired in most cases to provide two-circuit working.

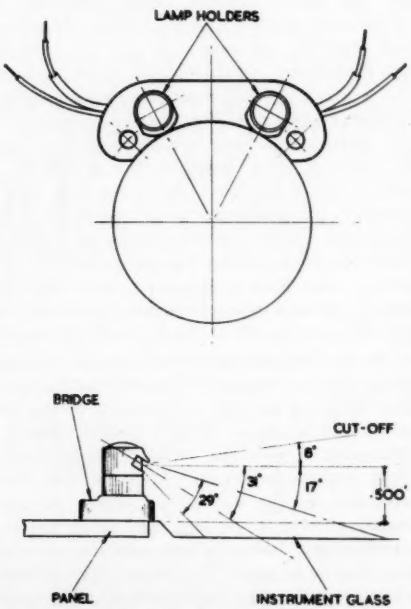


Fig. 11. The pillar lampholder system.

(3.3) Integral Lighting

The idea of building the lighting into an instrument has been advanced a number of times, and has been used on various instruments. One example of this method is the Kollsman screw-type lamp which has been used for sextants and some magnetic compasses and to a limited extent in certain designs of voltmeter. The lamp itself is rated at 3 volts 1.1 watt and its general shape aud application are illustrated in Fig. 13a. It is of interest to note at this stage that the low voltage employed on the filament generally means that some ballast resistor has to be fitted inside the instrument, or provided externally, to enable the lighting to be adapted to the normal 28-volt supply. The rated life of this lamp is only ten hours, and its use is therefore restricted. It cannot be built into the instrument completely and must for obvious reasons be fitted on the front face, where it is readily accessible for re-lamping. As indicated in earlier sections, there is little doubt that in order to get the best possible results the lighting has to be designed with the instrument, and built into its construction. Only in this way can the essential pointers and figures

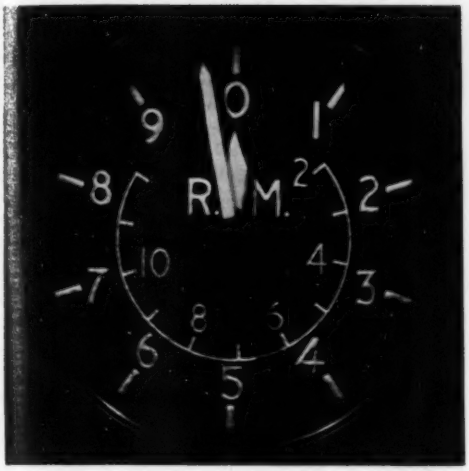


Fig. 12(a) An instrument lit by pillar lighting.

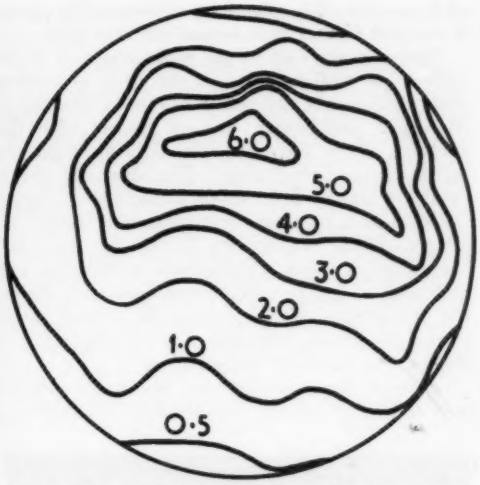
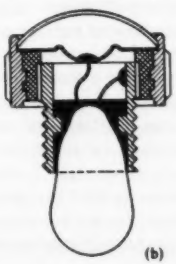


Fig. 12(b) Iso-foot-lambert diagram of the instrument in Fig. 12 (a).

be illuminated without scattered lighting. One example of such an application, using a fair measure of existing equipment of the types described in section 3.1, is the Kelvin & Hughes Attitude Indicator which is described in Fig. 14. One problem with some instruments is that they are pressurised, and in order to avoid throwing the instrument away or sending it back for service when the lamp fails, the lamp must either have a guaranteed life equal to that of the service period of the instrument, or be capable of being changed from outside the instrument without breaking the seal. A further alternative is to have an external arrangement for rapidly changing the supply from one interior source to another. These are just suggestions for the instrument designer. One practical attempt to meet this problem is a design for a new lamp, a robust aircraft version of the Kollsman screw lamp combined with a sealed holder. This lamp is called for functional reasons the "Limpet" lamp, and the design is shown in Fig. 13(b). The lamp is available in the 28-volt rating, and is similar in other characteristics to the 28-volt Midget Panel lamp. The holder, together with the lamp, is also shown in Fig. 13(c), and provides a sealed filter assembly which is mounted in the instrument case, the position being chosen to suit illumination of the dial. In view of the longer life and more robust construction of the lamp, this position need not necessarily be on the face of the instrument.

(4) Practical Applications to Cockpit Lighting

Having described the methods, we can consider the approach to the lighting of a typical cockpit. A survey of the geometry and seating arrangements for the occupants is an essential guide to the methods to be selected. A typical tight packed arrangement is shown in Fig. 4 with first and second pilot in front, and the engineer at the rear



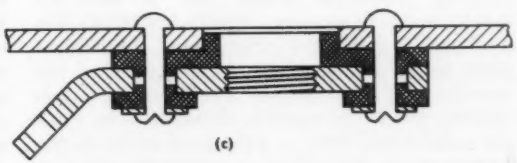


Fig. 13 (a) Kollsman screw lamp.
(b) Limpet lamp.
(c) Limpet lampholder.

of the second pilot. The Radio Operator/Navigator is situated farther back behind the first pilot.

Every square foot of the walls and roof of the cockpit, as well as parts of the floor, is covered with instruments and panels needing illumination. The most satisfactory way of dealing with this problem is to integrate the lighting with the layout at the initial stages, providing the opportunity to arrange the various surfaces to be illuminated in such positions that unwanted images are absent. This opportunity is all too rare but sometimes a major modification is involved and new systems can be applied retrospectively during the conversion. In most cases the aircraft panel layout is already complete and consideration of the lighting has been left until last.

Of these three possibilities, the last condition does not allow for the redisposition of equipment

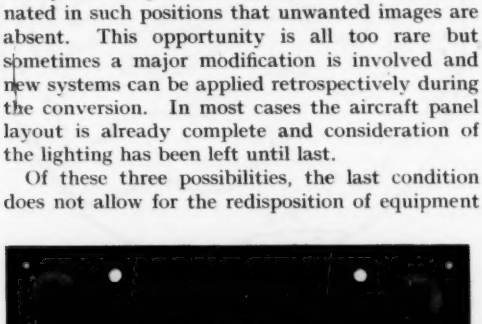


Fig. 14. Self-illuminated altitude indicator.

to enable the most efficient lighting to be applied, and lighting must usually be effected by the addition of pillar lighting to the instrument panel. Existing instrument fixings may be used for bridges and the minimum of holes drilled in other positions for individual pillar lamps. Individual pillar lamps are also held on any parts of the consoles and other control panels where flood-lighting cannot be applied efficiently. In some cases, the result may be quite good as far as the lighting of the equipment is concerned, but it is inevitable that a great deal of superfluous information is provided by unnecessary illumination of expanses of metal panel and aircraft structure, not to mention screw heads and other constructional features.

Where an aircraft layout is to be modified, it is possible to take advantage of the fact that panels have to be remade and layout can be arranged to give a more satisfactory pillar lighting scheme, avoiding the proximity of pillars to switch dollies and other controls. Auxiliary equipment on consoles may be replaced by up-to-date versions which will in all probability be fitted with trans-illuminated panels. The opportunity then exists for other areas to be brought into line by adding sections of trans-illuminated panel.

(4.2) Console and Floor Panels

After this general consideration, one can first examine the trans-illuminated equipment on the side consoles and floor panel. This consists of a mixture of separate self-contained units usually with built-in lighting and groups of individual controls, switches, warning lamps, etc., which are laid out in a particular pattern according to their use.

The variety of shapes and sizes of these small parts generally defies close packed arrays, which is an advantage in providing panel lampholder positions. It is nevertheless important to consider grouping relative to the light sources for explanatory legends. The supporting framework generally encroaches on the edges of separate panel sections to about 0.7 in. and as this area is not suitable for mounting lampholders (without mutilation of the support) the space can be usefully taken up with legends which need more room such as titles applied to groups of switches, etc.

Using the standard 3-16 in. thick trans-illuminated panel, it is found that about 15 lamps to the square foot gives an adequate amount of illumination without exceeding the 7 to 1 ratio (specified in R.A.F. Specification E.L. 1818, para. 3.7) between brightest and dimmest parts. This lamp density appears to hold good for panels with an average concentration of switches and equipment. In sparsely equipped panels, a reduction of lamps may be effected, spacings up to four inches being not uncommon. The possibility of failure of some part of the electrical system must not be overlooked, and to this end, the panel lamps may be wired in two circuits connected to separate busbars or main fuses. As it is not mandatory to meet the 7 to 1 ratio with either circuit separately, the division of the lamp positions is not critical but extra lamps will be required to avoid complete blackout of certain vital parts of the panel when one circuit is switched

off. Choice of these extra positions must be carefully considered to avoid unduly bright spots when both circuits are in operation.

Having placed the lamps in positions determined by observation of the relative areas to be illuminated and the probable effect of holes through the panel, further trimming of the lighting levels may be accomplished by treatment of the rear surface.

(4.3) Flying Panels

The greatest concentration of instruments of the dial and pointer type occurs on the flying panels, and in view of the restricted area and limitations of viewing angle, these instruments are placed very close together. The relative positions of the various instruments are governed by flying requirements, and follow a fairly common pattern. In preparing a lighting scheme using the transilluminated panel method, the choice of lampholder positions may make it necessary to redispose some of the instruments up to amounts of half an inch or so, but movement of this order does not appreciably alter the aspect of the display.

The vertical dimension of the panel is generally limited and in practice there is little opportunity to place lamps immediately above instruments, but diagonal positions are more readily available and give the most satisfactory arrangement for lighting. Wherever possible round holes are cut in the transilluminated panel to expose the face of the instrument, and the edges of the hole bevelled and polished to the appropriate angle to refract the light from adjacent lampholders on to the parts of the dial carrying inscriptions. The smaller instruments are almost always treated in this way, and light from two or three lamps is allowed to fall on the dial, the parts of the bevelled edge which are not required to transmit light being coated with black vinyl paint.

To obtain an even spread of light on the larger instruments the bevelled refracting edge is cut on a radius whose centre is approximately that of the lampholder. Thus all rays pass through the refractor at normal incidence in the plane of the panel, being equally refracted downwards on to the dial and avoiding the compound angle effect of the plain conical hole.

It is desirable to fix four lamps in diagonal formation for each of the larger instruments, using positions which will not give objectionable reflections from the glass of the instruments. Where instruments are well up under the coaming, all four positions may be used, but lower down the panel the acceptable positions will be determined by the geometry of the cockpit and the number of occupants.

All instruments do not exhibit the same depth of dial measured from the front face, nor are the markings or indicia in identical positions or of equal size and whiteness. The first circumstance is provided for by the choice of angle of bevel and the second by controlling light transmission by treatment of the panel surface in one or more ways. To avoid unwanted light escaping from the bevelled edges, the visible part of the back surface is rendered almost invisible by bonding black plastic to the rear of the transilluminated panel. No glass or solvents may be used in this bond, as these tend to craze the surface of the acrylic plastic with obvious results.

When the layout of the instruments is completed, the various legends around the switches and indicators on the panel are treated as in console panels.

As an alternative method the flying panel may be equipped with pillar lighting bridges and individual pillar lights used to illuminate the legends and indicators. In view of the fact that the bridges are arranged to illuminate the instrument from the top corners, no special precautions are required as far as reflections on the windshield and canopy are concerned. There is, however, a greater amount of light thrown on to the floor of the cockpit, and the coaming should be adequate to prevent reflections from the floor appearing in the windshield.

Both transilluminated panel and pillar lights can be wired to give two-circuit lighting.

(4.4) Roof Panels

The lack of space inside the cockpit makes it necessary to use the roof for a considerable amount of equipment, and transillumination can here be applied with great advantage. Lighting of any other sort, using an external light source, can be a decided nuisance in such a position due to physical obstructions.

(4.5) Engineers' Panels

The engineers' panels are generally situated on the right-hand wall of the aircraft, and curve up from knee-height to well above the operator's eye level. Particular care must be taken to ensure that there are no reflections in the windshield from the edge of instrument openings, and to avoid dazzling the second pilot if he has occasion to look backwards over his shoulder to check the information given on the engineers' panel. These panels

abound with fuel diagrams and electrical diagrams which incorporate magnetic indicators and ordinary instruments, and plastic panels can be used to very good advantage in these situations. Floodlighting would prove to be very difficult, as the lamps would either have to be placed in unsuitable positions along the edges of the panel, or of necessity encroach on the working space in front.

(4.6) Navigator's Equipment

At the navigator's position, practically all the equipment supplied will already have plastic panel lighting fitted, and the only requirement is that some care be exercised in the positioning of the items to avoid the possibility of reflections which may affect the first or second pilot. Some floodlighting must be provided at this point to enable the navigator to carry out his desk work, which involves writing, but it will be necessary to keep the illuminated area down to the minimum.

(4.7) Emergency Lighting

Most of the plastic panels require some form of emergency or standby lighting in the event of the normal supply failing, and if the total failure of the generating equipment be excluded, a suitable standby arrangement can be made by having half the lamps in each panel on a separate supply. In the event of failure of one or other supply, the display will be reduced in brilliance, and become somewhat uneven, but will still use essentially the same kind of light. Adjustment to the dimmer control will usually enable the maximum use to be made of the panel as full brilliance is not often employed for night flying. This method of emergency lighting can also be applied to plastic instrument panels, although it is often possible to provide a limited amount of red floodlighting, providing the coaming projects sufficiently far beyond the flying panel to accommodate the lamps.

(5) Future Trends

(5.1) Barnacle Lampholders

With the tendency to introduce instruments of uniform size, panel designers can pack instruments together leaving no room for lampholders in the backplate, and even little space for the leads from bridge-pieces. A lampholder with its conductors built into the plastic panel is one answer, and special material with a conducting layer is now produced (Fig. 15). A special lampholder has been designed which projects slightly more from the front of the panel, but it is not so obtrusive as appears at first sight, and it has the undoubted advantage of complete freedom in the choice of position.

It will be seen from Fig. 15 that the plastic plate is supported at a short distance away from the metal backplate, and that the lampholder itself is carried completely in the panel. The plastic panel is constructed with a white or black layer on the back, then a layer of copper foil, followed by a further insulating layer, usually black vinyl. The electrical circuit is therefore from copper foil through the flange of the body, through the cap, through the spring to the centre contact of the "pea" lamp. The flange of the "pea" lamp is in contact with the metal lining of the filter, and the current is then carried through this metal lining to the point of contact with the backplate.

To ensure correct spacing of the plastic panel from the mounting plate, special bushes are provided which carry captive screws, and these in turn engage with riveted screwed bushes in the instrument panel. Any suitable position for these fixing devices can be chosen which does not interfere with equipment on the back of the panel, or the engraving on the front of the plastic.

The lampholders can now be placed at any desired position on the panel without reference to the backplate, and fixing positions can be chosen with reference to the general shape of the panel.

(5.2) Grey Panels

Tradition has it that equipment in cockpits is black. With floodlighting this is essential. It is obvious that there is some room for improvement and the trend is shown by the present use of sea-grey knobs. It is only a short step from this to the condition where the whole of the panel is in some more attractive colour, limited only by the contrast which is available between the basic colour and the white engraved letters on the face of the panels. Admiralty grey panels to B.S.S. 381c Colour 632 have a much more comfortable appearance and the daylight contrast is quite good, being 5.5 to 1 against 13 to 1 with black. In the interests of appearance, grey caps are used on the filters, and these are also equipped with grey light seal washers. The night appearance is of course exactly the same, showing illuminated red letters against a dark background, but with the important difference that controlled general lighting can give shape and form to the panels and destroy the effect of "floating images in a black hole."

(5.3) New Light Sources

One future possibility with some attractive features is the use of electroluminescence in some

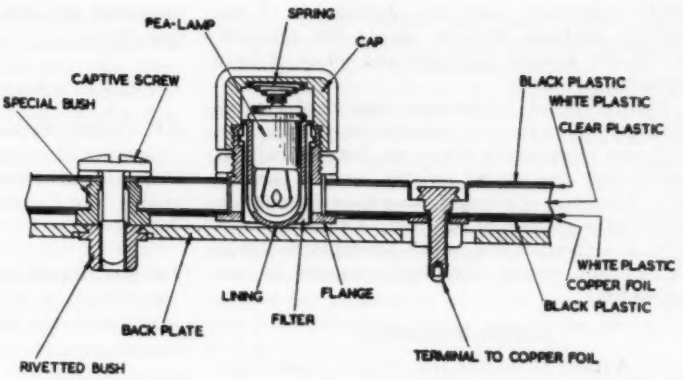


Fig. 15. Barnacle lamp-holder system.

form for the lighting of instruments and panels. Its great attraction is that these sources are, by their nature, very robust and have a long life. It is easy enough to replace the dial itself by a suitable electroluminescent panel but lighting the pointer is difficult to achieve except by the use of special trailing leads or rubbing contacts to carry the supply. One alternative is the use of silhouette lighting but that in itself is unattractive because it involves large illuminated areas if a full instrument panel is in use. The most attractive suggestion as yet made is to use an electroluminescent light source in the form of an annular disc which can be mounted on the front surface of a plastic sheet as used in the transilluminated panel.

One successful attempt has recently been reported from the United States in which the pointer of the instrument is manufactured completely from acrylic plastic in such a manner that light is piped up from the bottom of the pointer along to the indicator portion which is frosted to render the light visible. Certain recent developments in instrument manufacture using servo indicators, have displaced some of the more fragile moving coil and pointer arrangements. This enables a heavier pointer to be used, and therefore makes the application of light to the pointer much more of a practical proposition.

(6) Conclusions

We would like to draw from this study some conclusions on the future pattern of aircraft instrument lighting, but the position at the moment is far from clear. There is strong pressure from the aircraft industry for a complete system of integral lighting. This entails redesigning every existing instrument because at present they are all dependent upon exterior sources, with the possible exception of a few instruments like the Kelvin & Hughes Attitude Indicator. The hard facts are that, for some years to come, only a small proportion of the instruments will have their own lighting. The first advance will be the lighting of groups of instruments such as the Kelvin & Hughes Flight Data System Display. The quickest way to bring the other instruments into line would be to modify them by changing to transparent bezels or top-hat cover glass construction, and then the instruments could be inserted into the transilluminated panel, when they were available, with marked improvement to their night time presentation. Transilluminated panels lend themselves far more than any other system to this gradual changeover from exterior to interior lighting, and even after the instruments have been dealt with there will remain a great variety of panels, lettering, switches, etc., which can only be lit satisfactorily in that way.

In order to co-ordinate all the foregoing suggested practice, it would be necessary to have an overall specification covering the whole of the aspects of cockpit lighting. The present existing specifications deal with some parts of the problem, and are to a large extent disconnected. Transilluminated panels, as applied purely to consoles, are covered by R.A.E. Specification E.L.1818, and the American Specification is MIL-P-7788, while instrument lighting is covered to a certain degree by American Specification MIL-L-25467A, and a draft R.A.E. specification. A full specification should cover the general level, range and ratio of illumination, of all the reference surfaces in the cockpit, and at the same time take into consideration the other visual aids such as indicator lamps, and relate these devices to viewing conditions. Limiting conditions for stray light seen from the

pilot's viewpoint, and the illumination of the various exposed surfaces should be specified, taking into account the finish and colour of these surfaces.

This proposed specification should also cover guidance to component manufacturers to ensure that new components which are designed will fit readily into the overall lighting system, particularly in the case of schemes using transillumination as the basic method of lighting. A brief example of such a specification, which attempts to define the limiting values suggested, appears in the Appendix.

Acknowledgments

The Authors thank the Directors of Thorn Electrical Industries Limited for permission to publish this paper, and their colleagues, in particular Mr. Lancucki, for their help during the preparation of the paper. They also wish to thank Mr. J. Lawson Russell and Mr. H. F. Ringe of the Ministry of Supply for their assistance.

Finally, they wish to thank the following firms for the use of photographs, and for their useful advice on various aspects of the work: Bristol Aircraft Ltd., Handley Page Ltd., The De Havilland Aircraft Company Ltd., Vickers-Armstrongs (Aircraft) Ltd., Smiths Aircraft Instruments Ltd., Kelvin & Hughes Ltd.

References

(1) C.I.E. Report—Zurich, 1955.
(2) H. Huxley—J. Sci. Inst. **23**, 234; (1946)
(3) Magazine of Light—**21**, 2 (1952).

Appendix

Skeleton Specification for Cockpit Lighting

(1) Lighting Requirements on Control Panel Surfaces

(1.1) Brightness

The level of brightness of all white *indicia* on trans-illuminated panels or instruments with lamps operating at 3.5 lumens surrounded by red filters should not fall below 0.05 foot-lamberts or exceed 0.75 foot-lamberts.

(1.2) Brightness Ratio

Individual panels and instruments shall be so illuminated that the ratio of brightness over the panel or instruments shall not exceed 7 to 1 when fitted with lamps as in 1.1.

The brightness ratio of groups of instruments controlled by one dimmer shall be not greater than 10 to 1.

(2) Colour of Light

(2.1) Control Surfaces

Lighting of control surfaces shall be red. The filters around the light sources shall be to transmission and chromaticity specified in B.S.1376, Class A.

(2.2) Self-illuminated Indicators

Self-illuminated indicators are required to be in other colours and filters or cover glasses shall have transmission and chromaticity characteristics specified as in table:—

White	B.S.1376	White Class B
Amber	,,	Yellow Class B.1
Green	,,	Green Class B
Blue	,,	Blue Class A

(3) Viewing Conditions

(3.1) Limiting Angle

The limiting viewing angle of all *indicia* on instruments shall be 40 deg. from normal on main instruments, and 60 deg. from normal on secondary instruments and on trans-illuminated control panels. The surfaces shall be so disposed that these angles are realised with respect to the normal position of the eyes of the observing crew member.

(3.2) Stray Light

Stray light from exposed light sources (or reflected from control surfaces) falling on the walls, floor and furnishings of the cockpit shall be such that the brightness of these parts shall not exceed 0.005 foot-lamberts.

(3.3) Reflection in Windshield and Side Screens

Stray light from exposed lamp sources shall not fall in the windshield or side screens in such a position as to cast reflections into the eyes of the pilots. Images of illuminated equipment should not be present where the placing of the panels can be adjusted to obviate these. Where the reflection factor of the glazing is of the order of 10 per cent. for the angles concerned, images will be acceptable.

(3.4) Contrast of Inscriptions and Background

Where black panels and surfaces are used, the contrast between background and inscriptions viewed in daylight should be more than 13 to 1 and when grey backgrounds are in use this ratio should exceed 5 to 1.

(4) Finishes on Control Surfaces

Reflection factor of white and black surfaces on trans-illuminated panels shall be not less than 65 per cent., and not more than 5 per cent., respectively. Grey surfaces shall have a reflection factor of less than 25 per cent.

(5) Safety Requirements

(5.1) Multiple Circuits

Lamps used in pillar and trans-illuminated panel systems should be wired in two separate circuits on each individual panel, and shall be so disposed that when one circuit only is in use, the inscriptions are all visible by adjustment of the controlling dimmer.

(5.2) Emergency

A few selected lamps shall be so connected that they may be switched to an emergency supply in the event of failure of all the main supply. The switch controlling this circuit shall have a luminous dolly.

(6) Equipment

Switches, non-illuminated indicators, and other equipment normally mounted in panels shall be so constructed that their positions are capable of being lit by trans-illuminated panels.

Discussion

Mr. J. LAWSON RUSSELL: The President has prohibited congratulatory remarks but I must say how refreshing it is to have a paper on this subject which has not come from a government establishment. Practically all the major contributions have come from our own Royal Aircraft Establishment, or from similar establishments abroad, with of course a bias towards military requirements, and I am very glad that others are now taking a serious interest in the matter.

I am going to add a little to the chaos Dr. Strange has mentioned by joining issue with him on the subject of red light. I think we have paid far too much attention to the last war requirements of the night fighter pilot. Dark adaptation was most important to him because his task involved seeing his target silhouetted against the sky on the darkest nights. In those circumstances the old self-luminous markings on the instruments were too bright and the U.V. system was introduced to enable the pilot to work at an even lower brightness. This was combined with a floodlighting system, and for this the colour red was chosen because research had shown that red light had less effect on dark adaptation than any other colour. This " Dual System " of red floodlighting and U.V. floodlighting was undoubtedly the best system in use during the war. (Incidentally 24-volt glow discharge lamps were used first and were replaced later by filament lamps.)

In actual fact there is very little difference in the effect of yellow light and red light on dark adaptation and it was only by the most careful testing that we could find any difference between the yellow fluorescent markings and red floodlighting and the difference was scarcely significant. I think it was Mr. Calvert who first suggested that the extra-foveal insensitivity to red light would mean that instrument markings and their reflections in the windscreen would be less distracting to a pilot looking out of his aircraft and this may well be a good reason for using red light.

Dr. Strange has quoted night landings as an example of the pilot requiring good night vision, but on modern aerodromes there is such a blaze of light that quite often the problem is to provide enough illumination for the pilot to see his instruments against the glare of the approach lights.

I think that a re-examination of the requirements for cockpit lighting is overdue and I hope someone will undertake this task, placing a little less emphasis on vision outside the cockpit and more on the efficient performance of the pilot's task as a whole. It might well be that, taking it all round, yellow is a better colour than red and that grey finishes to surfaces in the cockpit might be better than black, even when floodlighting is used. I was very favourably impressed by this arrangement in one aircraft I have flown in.

I think Dr. Strange is a little hard on floodlighting: nearly all the really good cockpit lighting I have seen has been done in this way, using visible light or U.V., but satisfactory floodlighting can only be achieved when the design of the cockpit is suitable. When it is not, and this unfortunately is often the case, we are driven to other methods.

The pillar system is primarily intended for military use. It was designed to be applicable to aircraft already in service and to give flexibility for modifications to the instrument panel.

Dr. Strange has effected great improvements in the plastic plate method of lighting instruments. This system is perhaps more suitable for civil aircraft which, I hope, are less subject to the need for modifications.

Integral lighting of instruments has been something of a pipe dream of the aircraft lighting engineer for many years, largely, I suspect, because it would transfer his worst headache to the instrument manufacturer. However, some very promising results are now being obtained. I have heard

good reports of the glass wedge system, which, like pillar lighting and the plastic plate for console panels, is an American development. I hope we shall soon have some British competitors in this field.

Mr. A. M. A. MAJENDIE : I would like to support Mr. Russell's remarks about whether dark adaptation is a real requirement. There is a great deal of evidence in the civil field that it is not. Against that I would say that we must always bear in mind the emergency case where a pilot wants to see as much as he can without external light, and I would be unhappy if a cockpit did not have the facility of dark adaptation for emergency use—but that is different from lighting for regular use.

A significant point is to what extent we ought to consider the seeing of instruments by day and by night as two different things. In daylight conditions we get environmental lighting by which we can see instrument panels, the pilot's seat, etc. This provides real environmental knowledge of where the instruments are set, and in moments of stress it helps the eye to find its way in the jumble of lights, switches and knobs.

I think it is psychologically right to give environmental lighting and for this reason I do not think integral light is sufficient. If we provide integral lighting, we still have to provide flood-lighting. Furthermore, we need high levels of ambient illumination in the cockpit for three reasons :

(*a*) One has been mentioned—landing over high intensity approach lights ;

(*b*) A second case is flight under thunderstorm conditions at night, when bright flashes are taking place outside the windows and you need all the light you can get on the instruments to cope with an eye that is blinded by these flashes ;

(*c*) In cases where one is taking off into sunlight, or flying at high altitudes in bright sunlight.

In such cases we need luminances up to perhaps 20 ft.-lamberts, and I think it is going to be difficult to provide this by integral lighting.

The American Kollsman wedge lighting has been mentioned. It has one disadvantage ; I do not think it is well known that, the path of a light ray being reversible, if you arrange the wedge so that the light is going to reach the face of the instrument by that means, you cannot light the instrument from narrow angles of incidence from under the coaming. If you get sunlight, in turning flight, playing on the instrument panel, you might under certain conditions have a bright instrument surround but with little or no light getting on to the instrument face.

Traditionally, red light has been used for warning indicators. Considering Dr. Strange's demonstration of red and green light, I wonder if a warning is seen reliably if red warning lights are in the peripheral region of vision ?

Finally, the use of fluorising material on the pointers of sensitive and complicated instruments poses a problem for the instrument manufacturer, and we on the instrument side would be delighted to see it thrown out.

As to whether integral lighting is a firm requirement in the civil field, I am not too sure, but I am certain there is going to be a continuing need for it in the military field.

Mr. J. A. SYLVESTER : The adoption of grey instrument panels raises a number of special problems for the lighting engineer. The experience gained from the production of one aircraft type using such a scheme has shown that floodlighting, with white and red light, is extremely hazardous.

Before acceptance of a new aircraft type, flying personnel include in their examination a lighting trial under conditions of full dark adaptation. In the case of aircraft with grey flying panels the tendency is for pilots to adjust the level of lighting to suit the panel as a whole, and thence examine individual instruments. The result of this is to give a false impression of the lighting efficiency, for generally the light intensity is set too low for good observation of detail. Thus, in so far as flood-lighting grey panels is concerned, a rather different attitude is needed by pilots who normally fly with the absolute minimum of lighting.

These problems become less acute when trans-illuminated panels are employed. Unfortunately, our experience is that civil aircraft suffer as many modifications to panel layouts as their military counterparts and thus such lighting is difficult to adopt. It could well be that, at this stage, trans-illuminated panels offer the best form of low intensity red instrument lighting for the constructor who is favoured with a large order for a fully developed aircraft type. However, in our experience, some additional carefully balanced frontal lighting is essential.

Integral lighting of instruments is now a definite requirement of the aircraft industry. One operator has already placed an order for a British aircraft with a contractual requirement that integrally illuminated instruments be employed. In the highly competitive field of civil aviation the American industry will naturally pursue any new development to the full, and in this instance our

own instrument engineers must not concede the initiative.

The difficulty of floodlighting instruments with a Kollsman wedge has been mentioned. This problem is known to us, and is one of the many we expect to encounter and overcome, with the adoption of integrally illuminated instruments.

A further requirement of the aircraft illumination engineer is that of providing a very high level of flight deck floodlighting in addition to the normal instrument lighting. Such lighting is to counter the very deep shadows obtained in certain climatic conditions and the installation of equipment to achieve this is definitely required. We would encourage component manufacturers to investigate this particular field of aircraft illumination.

Mr. P. F. Cook: I would like to raise the question of the illumination of controls. The position of a switch is often as vital an item of information as the indication of an instrument or the presence or absence of a light. I would like to ask the authors if the trans-illuminated panel improves the visibility of such controls to the same extent as it does the latter.

I was very interested in Dr. Strange's mention of electroluminescent lighting and in particular its high reliability. If there are a large number of light sources (as there may be in integral lighting) the operator tends to complain at the extensive servicing man-hours involved in the replacement of the tungsten filament lamps. On the other hand, if the light sources are too few the risk exists of large sections of the cockpit being lighted in a very inferior manner when there is a failure of lamps or circuits. I would like to ask what is being done about the reliability of the tungsten filament lamp. In the case of the electronic valves there have been most notable developments in the last five years on the score of reliability, and if integral lighting is to be successful similar improvements will have to be made in tungsten filament lamps.

Mr. Majendie: Could I make two further points? Firstly, one of the things we are not too sure about is whether red lighting has any effect on fatigue. The Americans did recently indicate there was some evidence that this was so. We have tried to find reasons for it, but I would like to know whether the lighting people can give any evidence of this effect, particularly any correlation with age. Secondly, on integral lighting it is important that people are not misled by what has been said. The opinion of North American operators on the use of integral lighting is quite divided, and some of the operators are strongly resisting it, while others are insisting on having it.

Gp. Capt. A. H. Humphrey: I would also like to support this argument that there is perhaps a dying requirement for full night adaptation to be continuously available to a pilot. Clearly in the military field there are realms in which this is necessary, maritime operations, tactical operations in support of the Army, etc., but I think the realms are becoming fewer and further between. I myself would be unhappy to see floodlighting disappear completely for precisely the same reasons as Mr. Majendie has mentioned, but that does not really alter my view that integral lighting should be the primary lighting for most aircraft of the future. I also am very fond of these grey panels.

Mr. H. R. Ruff: I much enjoyed the paper as delivered by Dr. Strange; it described in truer perspective the relationship between local or pillar lighting and floodlighting. In connection with the difficulty of references to cockpit floodlighting, a lot of earlier work was carried out during the war. As Mr. Russell stated, publications have mainly been from various government sources and much has not been published. The written paper gives an excellent account of the problems encountered in trying to get light from local lamps on to the right parts of the control panels and of the instruments. Since the paper covers mainly this method of lighting, perhaps the specification suggested, although covering some general points, should be regarded as being limited to this method.

I was concerned with the suggestion of possible dangers from U.V. floodlighting. It is so easy to support scares. We can measure accurately radiation from light sources over the whole U.V., visible and infra-red radiation and the biological effectiveness of different U.V. wavelengths has been studied extensively by the medical profession. Both from the point of view of the wavelengths of the U.V. radiation and the minute amounts required for exciting fluorescence on the instruments there should be no danger whatever from the near U.V. sources used for this work.

As the demonstrations have shown, it is possible by U.V. floodlighting to get visible light only from the indicating marks and pointers by restricting fluorescent marking to these points. In this way the maximum information can be obtained with the minimum of distracting light. In the paper it is suggested that this may make it difficult to locate the instruments, but it is so easy to have a

small amount of red floodlighting to do this that there is no difficulty whatever. The system can be applied with either grey or black panels which would not be so easy if visible floodlighting only were used.

I would like to support the authors' plea that whatever the system of lighting preferred, the earliest possible approach to the lighting engineer helps greatly the satisfactory solution of the problem.

Integral lighting has been mentioned by the authors and by Mr. Russell. When we were developing the U.V. plus red light floodlighting systems we tried electro-luminescence as an integral light source. A deep blue phosphor was used to form a light source in the form of a rim around the instrument dial. The marking of pointer and scales was in a phosphor converting the blue light into red. The instrument glass was tinted yellow so that no light from the source could be seen, leaving the indications in red. It was an interesting system but was regarded by manufacturers of the diverse and complicated instruments as difficult to install, and in addition we could more simply obtain the same effect with the U.V. and red floodlighting scheme.

MR. P. CHITTENDEN: This has been a very interesting paper but I would like to question the authors on the possibility of maintenance trouble arising with the large number of light sources which the system requires. With their permission, and that of the chairman, I would like to show a slide of the U.V. floodlighting which is in use on the B.E.A. "Viscount 800."

This slide shows the pilot's control panels which are illuminated by three 4-watt 6 in. woods glass fluorescent lamps and I think you will agree that it illustrates the very good definition which can be obtained by this method. One lamp is mounted centrally over the instrument panel and the two further lamps are mounted vertically at either side of the panel.

I would also like to refer to the specification. There is no mention in this of dimming, and as other speakers have already mentioned the question of night adaptation it does occur to me that some reference in this specification to the desirable limits of the maximum and minimum brightness of instruments would be very useful.

DR. J. BARNETT: On the question of the reliability of the tungsten filament lamps, R.A.E. issued a technical note a year or two ago which stated that there would appear to be no way in which the robustness of lamps could be improved. Rated voltage should be as low as possible and anti-vibration mountings should be used.

The 28-volts .04-amp lamp, which is the standard lamp on these panels, was originally American with a life of 350 hours, but we have no difficulty in making them in this country with a life of 2,000 hours.

THE AUTHORS (in reply): Regarding Mr. Lawson Russell's points, it was most interesting to hear the Service and Ministry of Supply views, and we are of course hoping that Mr. Russell's personal opinion about grey panels will carry some weight in due course with the R.A.F.

Mr. Majendie mentioned the question of the increase in light in cockpits and the possibility of altering the colour from the deeper red to a lighter, possibly yellow, colour. We are, of course, able to replace these lamps with lamps of different colour filters, and cover any customer's requirements. It appears that despite particular views put by Mr. Majendie and one or two others, there is still a large volume of opinion in this country in support of a fairly low level of red light.

Mr. Ruff brought out an interesting point that the specification appears generally to be limited to the type of lighting we propose. We have endeavoured, of course, to follow the most modern practice and discard such methods which as far as we know are not widely supported. The specification is purely a skeleton and we do hope that after you have had an opportunity to read the paper more closely we could hear your views on the possibility of including more items, such as the one that was mentioned on the question of dimming.

Regarding danger from U.V. sources, we have never considered there is a danger in its practical use in any form, but we do feel that the amount of illumination when limited to the indicia on the face of the instrument is hardly enough to give the pilot a comfortable idea of his cockpit, hence the addition of red lighting to the U.V. to supplement it. We further felt that the trans-illuminated panel method enables legends on that panel to be illuminated at the same time as instruments, and furthermore it gets over the difficulty of having a limitation on the actual amount of information available.

Mr. Chittenden mentioned the maintenance of lamps on these panels. Basically the lighted area is divided up into a series of large or small sections, each containing its own lamps. This ensures a general distribution of light and the distribution is far more effective than three or four sources

of floodlights that operate from various parts of the aircraft. Maintenance of the lamps is one of those things we are very interested in, and as far as we can see the miniature lamp is as good as other types of lighting in this respect. If one of the M.V. lamps fails you lose a large percentage of lighting of the panel, whereas the failure of a number of " Pea " lamps will not render the whole of the panel dark. The lighting will be lower in value, and to some extent uneven, but a control is there to rectify this condition. Lamps can be readily changed in flight, or serviced at the earliest opportunity.

Regarding specifications for dimming, we find in our consultations with various customers and their test pilots that there is a considerable divergence of views on what constitutes the correct level for operating a flying panel, and this is illustrated by the point made by Mr. Majendie that there is probably a good reason to have a high level of light. On the other hand, the moment we find ourselves discussing this matter with some people, they claim they fly with lamps turned down to 6 to 7 volts, which we personally cannot see.

We agree with Mr. Sylvester's point regarding the grey panel. If you illuminate a light-coloured panel with a general light, you are acutely aware of the distribution of lighting. On the other hand, we feel that the grey panel is of considerable use during the day-time when you are not using your artificial aids to vision. Sitting in an all-black cockpit must be very depressing and the grey is intended mainly as a method of furnishing the cockpit in a more pleasant manner, rather than providing an aid to illumination. Translighting which illuminates instruments and legends at the same time avoids the effect mentioned.

A further point Mr. Sylvester made was the question of integral lighting in America. We are unfortunately not able to sound the aircraft industry, but from what we learn from our associates on the other side of the Atlantic, we gain the idea that some instrument makers produce instruments illuminated from the edge of the panel.

Dr. Barnett mentioned reliability of the tungsten lamp, and I would underline that particular point here. We are required to produce these panel lamps to a specification which takes into account vibration, bump tests and other requirements, so that there is a fair degree of reliability compared with higher wattage lamps running often at higher voltages.

The position and colour of warning lights is important. We endeavoured to introduce that subject in the specification. There are, of course, fairly well-defined positions now adopted for these items, and I am quite prepared to add the point that red lights should be very carefully arranged with a view to edge vision. I had occasion a little while ago to sit in a cockpit where the warning lights were at different parts of the panel and in the right-hand seat I could not see a red light at the left hand side which was full on.

On the question of fatigue, it is known that at these low levels of illumination the eye can discard images which would at higher levels be seen out of the corner of the eye, and we feel that this must reduce the tendency of the eye to adapt continuously, with the result that it must have the effect of reducing fatigue. We have discussed this question with people concerned in sorties of 10 hours at a time in Coastal Command at a R.A.F. station where American aircraft were using red lighting. The general consensus of opinion was that it was quite satisfactory for that length of trip.

UDC 535.241 : 621.327 534.15

Ambient Temperature Effects in the Photometry of Fluorescent Lamps

By W. R. BLEVIN, M.Sc.

Summary

The dependence of the luminous and electrical characteristics of fluorescent lamps on the ambient temperature introduces complications in the photometry of these lamps. It is shown that if both the luminous flux and the electrical characteristics of a stable lamp are measured over a range of ambient temperatures, then on future occasions of burning within that range it is possible to deduce the luminous flux of the lamp from measurements of its electrical characteristics without requiring a knowledge of lamp or ambient air temperature.

It is well known that the luminous efficiency of fluorescent lamps is affected by changes in ambient temperature, maximum efficiency occurring when the temperature is about 20 deg. C. As the temperature decreases the efficiency falls off rapidly while as the temperature increases the efficiency decreases more slowly. Marden, Beese and Meister[1] have shown experimentally that this effect is almost entirely due to changes in the rate of emission by the discharge of ultra-violet radiation at the mercury resonance wavelength 2537Å.

More recently Jerome[2,3] has investigated the variation in the electrical characteristics of fluorescent lamps with temperature and has published results of detailed measurements on a variety of lamps operated at constant current. The luminous efficiencies of the lamps are shown to have maximum values for *lamp wall* temperatures within the range 35 to 50 deg. C, while the electrical impedance of each lamp passes through a maximum value at a somewhat lower wall temperature. The physical processes responsible for this behaviour have been discussed theoretically by Waymouth and Bitter[4].

The effect of ambient temperature on the efficiency of fluorescent lamps adds to the difficulty in specifying the luminous flux of lamps intended for use as photometric sub-standards. Two procedures have been widely used to reduce uncertainties from this cause. One method has been to maintain the flux integrating enclosure at some adopted reference temperature, but this procedure is of little value in calibrating lamps which are subsequently to be used in a laboratory where temperature control facilities are lacking. The other method has been to measure the ambient temperature at the time of each burning and correct the measured value of luminous flux to an adopted reference temperature, correction factors having previously been determined for each class of lamp or, if higher accuracy is desired, for each individual lamp. A disadvantage common to both of these methods is the difficulty in defining and measuring "ambient temperature" in the neighbourhood of a light source. The air temperature may vary from one point to another and irradiation of the temperature-measuring element by the source may introduce considerable errors. Ambient temperature is indeed such a vague term that there is little hope that it will ever be satisfactorily defined in a manner lending itself to simple measurement, and it would be advantageous to avoid measuring it altogether if possible. Since ambient temperature governs the characteristics of fluorescent lamps only in so far as it affects the *lamp wall* temperature, it would appear to be a better procedure to measure the wall temperature. However, measurement of lamp wall temperature is attended by similar difficulties and, moreover, in an intensified form.

The present paper describes the method used at the Australian National Standards Laboratory for taking ambient temperature effects into account. It shows that since both the photometric and the electrical characteristics of fluorescent lamps vary with temperature, one can dispense with the necessity of measuring the luminous output of each lamp as a function of ambient temperature and instead measure the output as a function of the lamp's electrical characteristics. The chief advantage is that the electrical characteristics, unlike the temperature, can readily be measured to a high accuracy and without ambiguity provided that the measuring instruments are chosen and used correctly [5,6]. In the initial standardization of a lamp its temperature must be varied by some suitable means to provide the range of electrical characteristics which may occur in future use of the lamp. Accurate knowledge of the temperature is not required, however, nor is any subsequent reference to temperature necessary. The method

The author is with the C.S.I.R.O., Division of Physics, National Standards Laboratory, Sydney. The manuscript of this paper was first received on September 10, 1957, and in revised form on December 23, 1957.

is applicable only if the lamp's characteristics are sufficiently stable and reproducible, but this is a prerequisite for standards purposes in any case.

Use of the Electrical Characteristics

It is a wise precaution in any method of photometry of fluorescent lamps to ensure that the ambient temperature is not less than 20 deg. C., owing to the rapid fall in luminous efficiency at lower temperatures. Our interest then may be confined to the ambient temperature range 20 to 30 deg. C. (the latter value being rarely exceeded under laboratory conditions) though the method described is not restricted to this range; the corresponding lamp wall temperature range depends on the type of lamp, but can be shown from Jerome's results[3] to be about 35 to 50 deg.C. for lamps operating at rated current.

Jerome's measurements on lamps operated at constant current show that the electrical characteristics of a given lamp take a different set of values for each temperature over the range 35 to 50 deg. C. It follows that if both the electrical characteristics and the luminous flux of a lamp are measured over this temperature range, then on subsequent occasions of burning in the same circuit or in an equivalent circuit, measurement of the electrical characteristics is alone required to make the flux known.

Lamps intended for use as photometric standards are usually calibrated not at a fixed current but at a fixed lamp wattage. Although Jerome has not made any measurements at fixed lamp wattage, his results indicate that in this case the lamp current would increase with wall temperature over the range 35 to 50 deg. C. and the lamp voltage decrease. I have made some measurements of the magnitudes of these variations, as follows.

The lamp under test is placed centrally along the axis of a copper cylinder of length 6 ft. and internal diameter 6 in., whose inside wall is blackened. The temperature of the cylinder is varied by passing temperature-controlled water through copper tubing wound helically around the cylinder. A colour-corrected photovoltaic cell connected in a Campbell-Freeth circuit is used to measure changes in the luminance of a central region of the lamp wall. Each time the enclosure temperature is altered, sufficient time is allowed for the lamp to regain stability before its luminance and electrical characteristics are measured.

Fig. 1 shows the results obtained with a typical 4-ft. 40-watt hot-cathode lamp operated *at rated power* in series with a suitable choke, the electrode at each end of the lamp having been short-circuited after starting. Values of lamp luminance, voltage and current are plotted against the temperature of the circulating water. In Fig. 2 the lamp luminance values of Fig. 1 are plotted directly against the lamp current, showing that on future occasions of burning the luminance can be deduced from a simple measurement of the current. In practice either the voltage or the current can be used as a measure of the thermal state of the lamp.

Measurements on 2-ft. 20-watt and 5-ft. 80-watt hot-cathode lamps have indicated that their electrical characteristics also are sufficiently

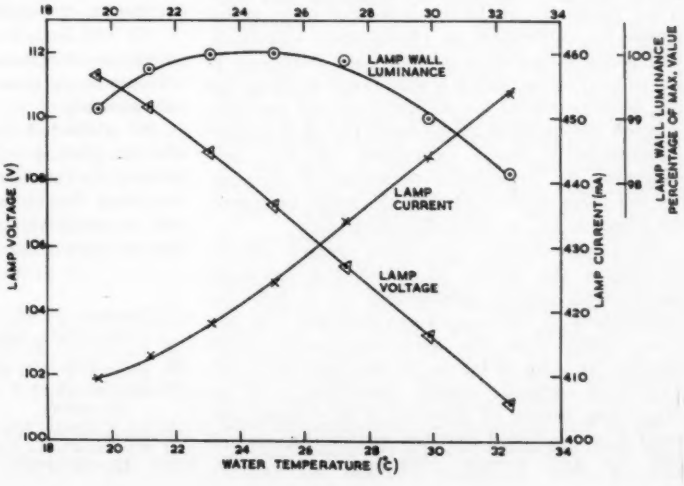


Fig. 1. The wall luminance, voltage and current of a 4 ft. 40-watt fluorescent lamp run at constant lamp wattage (40-watts), plotted against the temperature of the water passing around the lamp enclosure.

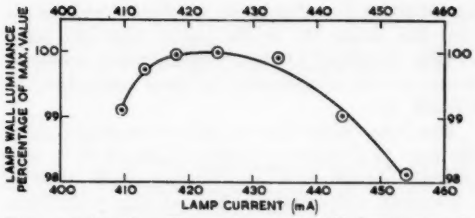


Fig. 2 (above). The values of wall luminance in Fig. 1 shown plotted directly against the lamp current.

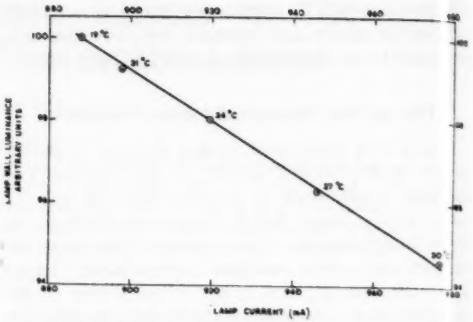


Fig. 3 (right). Lamp wall luminance of a 5 ft. 80-watt fluorescent lamp plotted against lamp current. The measurements relate to a lamp operating at rated power at the ambient temperatures whose approximate values are shown.

dependent upon temperature for the lamps to be standardized in the manner described.

Although ambient temperature changes within the range 20 to 30 deg. C. have caused only small variations in the luminous efficiency of the lamp referred to in Figs. 1 and 2, this is not so with all lamps. Of those examined, the 80-watt lamps have shown the greatest variation of luminous efficiency with temperature. Fig. 3 shows the wall luminance of a typical 80-watt lamp plotted against lamp current; the measurements have been made with the lamp operating at rated power at various ambient temperatures. The luminous efficiency of these 80-watt lamps when operated at rated power reaches its maximum value at an ambient temperature somewhat lower than 20 deg. C.

The new technique obviously requires the usual precautions of seasoning fluorescent lamps for some hundreds of hours, selecting only stable lamps for calibration as photometric standards, and recalibrating after limited use. Although in the present investigation a wide range of lamps has not been examined for stability, several specially selected hot-cathode lamps have shown adequate reproducibility when calibrated by the new technique on consecutive occasions of burning. On the other hand cold-cathode lamps examined have been found too unstable electrically.

Some experiments have been carried out to investigate the extent to which the luminous output-lamp current relationship of a lamp is independent of the lamp's environment. It has been verified that the same relationship holds whether the lamp be burned in the relatively small cylindrical enclosure already described or in an integrating sphere of diameter 6 ft.; from this result it is concluded that the relationship should hold for any normal photometric enclosure. However, the method described is not applicable under abnormal conditions which seriously upset the temperature distribution of the lamp, it having been found that in such cases the light output of a lamp is not a function of its electrical characteristics only.

Conclusion

It is suggested that in using fluorescent lamps as photometric standards it is unnecessary to measure or specify the ambient temperature. Instead, the luminous output may be measured as a function of lamp current or voltage, the lamp being run at rated or other specified power. The steps involved in calibrating a fluorescent lamp as a sub-standard of luminous flux are then as follows:

(i) The lamp is operated at specified power in a temperature-controlled enclosure; the ambient temperature is held steady at a number of values over a range of about 20 to 30 deg. C. and fractional changes in lamp wall luminance are plotted against the lamp current. Precise temperature measurements are not necessary.

(ii) The lamp is operated at the specified power inside an integrating sphere, its luminous flux and current being measured at the prevailing ambient temperature.

(iii) Provided that the ambient temperature in the integrating sphere is within the range 20 to 30 deg. C, the above two steps allow the lamp's luminous flux to be plotted against lamp current. On future burnings in an equivalent circuit the flux is known from the current.

References

(1) Marden, J. W., Beese, N. C., and Meister, G., Trans. Illum. Engng. Soc. N.Y., **34**, 55 (1939).
(2) Jerome, C. W., Illum. Engng. **49**, 237 (1954).
(3) Jerome, C. W., Illum. Engng. **51**, 205 (1956).
(4) Waymouth, J. F., and Bitter, F., J.appl.Phys. **27**, 122 (1956).
(5) I.E.S. Guide, Illum. Engng., **49**, 267 (1954).
(6) Blevin, W. R., Trans. Illum. Engng. Soc. (London), **22**, 164 (1957).

UDC 628.978

Lighting and Safety in Building Operations and Works of Engineering Construction

By J. GORDON SCOTT

Summary

The provision of inadequate temporary lighting, or faulty or unsuitable lighting equipment on building operations or works of engineering construction has been the direct cause of many serious accidents. This paper has been prepared in an endeavour to emphasise that such provision is illegal, and also to suggest methods of lighting that will allow work to be carried on safely.

The legal responsibilities of both contractors and workmen are discussed, as are typical hazards and accidents. The point is made that supervisors should be educated to accept only the highest standards of lighting—both fixed and portable—and that they should impart such knowledge obtained, by example.

(1) Introduction

The particular concern of this paper is with accident prevention and the safety of persons employed on building operations and works of engineering construction at times when the work is required to be done during the hours of darkness, or when work is to be done inside buildings where the natural light is obscured, or in excavating or tunnelling operations.

By the very nature of such work the lighting will have to be artificial and will invariably be of a temporary nature while the major portion of the work is being carried on.

Since 1950 there has been a steady increase every year in the number of accidents reported from building operations: 12,340 (including 213 fatal accidents) in 1951 to 14,561 (including 184 fatal accidents) in 1955. The relevant figures for works of engineering construction are 2,116 (37 fatal) and 2,012 (39 fatal).

As building operations and works of engineering construction are normally carried on during the hours of daylight, it is reasonable to presume that the majority of accidents occur when seeing conditions are reasonably good. It can be assumed therefore that when work is being carried on with the assistance of artificial light, the accident rate will depend substantially on the quantity and quality of the light; and not only must lighting be provided, but it must also be provided safely.

The standards of lighting will, of course, vary considerably with different types of operation, and as work progresses it is quite probable that the installation, fittings and power supply will have to be modified from time to time to suit changing conditions. As an example of this, when the preliminary excavations and levelling work for a large power station were in progress, it was necessary to provide high standards of general lighting over a wide area; towers were erected at several strategic positions on which floodlights, similar to those now seen at many football grounds, were provided. This was found to be satisfactory until the structure started to rise; whilst there was still excellent general lighting there had to be constant supervision to ensure that the various internal sub-divisions were kept properly illuminated as the building progressed.

With the building of a structure such as a power station, the provision of artificial lighting does not normally present many difficulties; the areas to be illuminated are for the most part extensive, and can normally be covered by good general illumination. Difficulty has been experienced, however, during the building of multi-storey buildings for flats and offices, especially at that floor next to the top one under construction. The top or outside part is usually well lighted by the general lighting from the floodlights, and the second floor down has the temporary cables secured into position. The first floor down, at least for a few nights, is usually served by portable lamps suspended from rails or hooks. There are rarely sufficient portable lamps of an approved type to supply all rooms where work may have to be carried on, and it is frequently the case that workmen are injured due to using improvised portable lamps consisting in the main of non-earthed metal or bakelite pattern lampholders connected to a pair of flexible wires. Such make-shift arrangements are dangerous and should not be tolerated under any circumstances. (See Fig. 1.) There are specially designed, fully protected,

The author is with the Midland Employers' Mutual Assurance Ltd.
The manuscript of the paper was first received on December 3, 1957. The paper was presented at a meeting of the Society held in London on March 11 1958.

Fig. 1. This lead and plug board was used by a building contractor to provide supply to a hand lamp which had an unprotected lamp holder. The plug top was of the rubber type. The earth pin had been removed so that it was possible to deform the plug to allow the remaining pins to enter any socket outlet on the site. The lamp holder became "live" and an employee received a fatal shock from the unearthed hand lamp.

portable lamps readily available from several manufacturers.

Where tunnelling is being carried on, or deep foundations are being excavated, the provision of good lighting is essential, not only because of the normal hazard of working in confined spaces where there may be many obstacles, but also to enable the persons employed to see clearly the type of ground or run of rock strata through which they are working, enabling any necessary propping to be done at the earliest opportunity, so that adequate precautions can be taken to prevent falls of rock or other material which could cause accidents.

With the new road improvement and trunk road schemes which have recently been approved by Parliament, and the urgent need for this work to be completed with the least possible delay, it is quite certain that much of the construction work will have to be carried on both by night and by day. It is envisaged that this work will include new bridges, extensions to existing bridges, and railways, the diversion of rivers and canals, and the construction of fly-over junctions, all of which will present their own problems in providing safe working conditions during the hours of darkness, for it must be remembered that normal traffic must be interfered with as little as possible.

When referring to general lighting on sites it should not be overlooked that where there is a right of way for the general public—as is often the case on housing estates—there is a legal responsibility to provide such lighting as will enable any person to pass with safety.

(2) The Application of Factories Acts and Regulations

By virtue of Sections 107 and 108 of the Factories Act, 1937, the provisions of that Act in their application to building operations and works of engineering construction have effect as if any place where such works are carried on is a factory, and any person undertaking any such operation or work to which the Act applies is the occupier of a factory. Other adaptations and modifications may be made by Regulations made by the Secretary of State[1].

This means, briefly, that as far as the administration of the Factories Acts is concerned, a building operation or work of engineering construction is a factory, and all relevant Regulations can be enforced, the most common Regulations concerned being the Electricity Regulations, the Woodworking Machinery Regulations, and the Locomotive Regulations.

(2.1) Building Operations

With powers given under Sections 107 and 108 and also Sections 40 and 60, Special Regulations can be made. With these powers, Regulations have been issued known as the Building (Safety, Health & Welfare) Regulations, 1948[2]. These, as the name implies, deal specifically with building operations and are to ensure that such work is done safely. The particular Regulations from this Code which come directly within the scope of this Paper are few.

Regulation 4 states the obligations and duties of contractors who undertake this kind of work, and also the duties and responsibilities of persons employed on building sites. It should be mentioned here that these duties and responsibilities are very real ones, and when carried out properly contribute greatly to the safe working conditions.

Regulation 5 requires among other things that there shall be safe means of access so far as is reasonably practicable to all places where any person has at any time to work. Any working space and access to that space should, therefore, be always provided with suitable and adequate lighting. Whilst, presumably, the statutory periodic inspections of scaffolding, etc., will normally be done during daylight, there may be occasions when these have to be done at night. In any such instances adequate lighting should be provided, and as a precautionary measure it is suggested that a second examination take place as soon as possible with the advent of good daylight.

Regulation 91 requires that every working place and approach to a working place, every place where

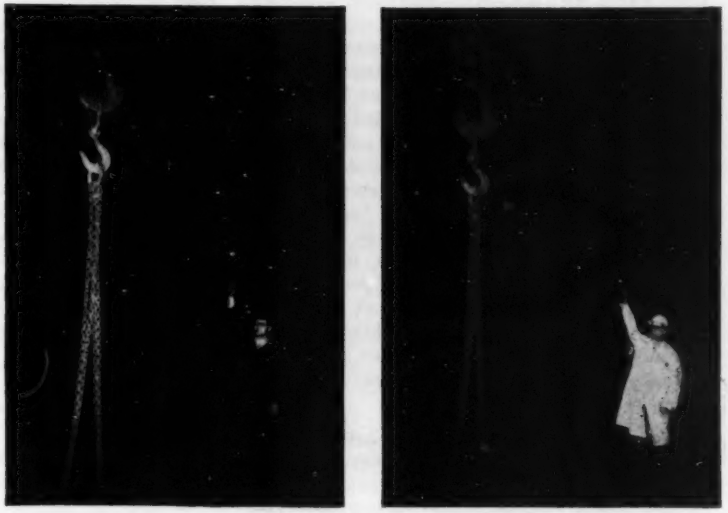


Fig. 2. Showing how the signaller to a crane operator is made more conspicuous when light coloured overalls are worn

raising or lowering operations with the use of lifting appliances are in progress, and all openings dangerous to persons employed, shall be adequately and suitably lighted. This Regulation has a very wide application and can possibly be invoked should there be any accident on a building site during the hours of darkness, or in places not served by natural lighting.

As the Regulation mentions two dangers in particular, i.e., where lifting appliances are being used, and openings in floors, attention is drawn to Regulation 50(3). This requires that the operator of any lifting appliance must have a clear and unrestricted view of the load, or, if this is not possible, there shall be one or more competent persons to give the necessary signals to the operator. There have been many serious accidents caused by a breach of this part of Regulation 50 and it is most important that care should always be taken to ensure that the lifting hook and the load are clearly illuminated when the load is in suspension. The provision of suitable lights secured at the jib head and directed vertically downwards normally achieves this. The signaller should also be clearly visible and necessary precautions should be taken so that it will be quite certain that signals cannot be misunderstood due to glare from other lighting in the vicinity. Also, with this aspect in mind, it should be remembered that the visibility of a signaller depends to a large extent on the contrast of the signaller to his background, and as the background will nearly always be a dark one, it is suggested that such men should be provided with light-coloured overalls. (See Figs. 2a and b).

The scope of these Regulations includes the requirement that hoists should always be worked safely. Whilst the operator of any hoist should, if possible, have a clear and unrestricted view of the cage or platform (if this is not practicable, there should be an effective signalling system), conditions should be such as to enable him to stop the hoist cage or platform at the appropriate level in the hoistway. It is obvious, therefore, that lighting at these working spaces must be of a very high standard. There should as far as possible be a complete absence of shadow, especially at the loading and unloading levels. Illumination should be such that when the cage or platform is passing any landing, the lights are not obscured or cause any shadows from the moving cage. It has been found that a satisfactory method is to provide lighting at each side of the landing gates; this should illuminate that part of the hoistway where the cage or platform would stop for loading and unloading from the landing.

The area of approach to the hoistway at each landing should also be well lighted and kept free as far as possible from obstructions such as scrap material, cement, wheel-barrows, bricks, etc.

The provision of red "Danger" lights at each landing is useful in warning persons to take care. One contractor has had notices fitted at each landing in the form of red glass plates illuminated

from behind with DANGER—HOISTWAY painted on the glass.

It is sometimes not clearly understood that the demolition of a building comes within the scope of the Building Regulations (Regulation 79). Whilst it is usual for this work to be carried out in daylight, there are occasions when nightwork is necessary. In such circumstances there should, of course, be good general lighting extending over a wide area surrounding the whole of the demolition site and, in addition, there should be a system of warning lights at each approach to the area. Many contractors have found that because of the extreme danger during such work it is also necessary to have a man employed at each approach to give warning to persons and vehicles passing near the point where demolition is taking place.

(2.2) Works of Engineering Construction

Whilst up to the present time there have not been any special Regulations approved for works of engineering construction, preliminary Draft Regulations were published in 1951, and these have been reprinted since[3]. The proposed Regulations are so comprehensive (152 Regulations in all) and cover such a wide field that it has been considered advisable by the authorities to divide the Code of Regulations into sections and re-issue them separately. It is understood that there will be seven sections in all; the first has already been published and deals with work in compressed air chambers.

The requirements for standards of lighting are identical to those in the Building (Safety, Health & Welfare) Regulations, 1948, which have been referred to in detail above.

Whilst there is no legal responsibility for a contractor to comply with these Draft Regulations, it is suggested that contractors should make themselves familiar with them, as it is expected that they will be eventually approved with little alteration in wording, and none in intent.

(2.3) Electricity Regulations

As mentioned in the first paragraph of this section of the paper, both building operations and works of engineering construction are considered as factories in so far as the application of certain sections of the Factories Acts is concerned, and certain Regulations are enforced, the most important of these being the Electricity Regulations[4].

Whilst it is hardly necessary to stress the particularly onerous conditions of employment associated with building and construction work, the temporary nature of the jobs and the fact that they are in large part out of doors make it particularly important that appropriate measures be taken to safeguard the men who handle or have anything to do with electrical apparatus on sites.

The Regulations apply in full, with no special provisions for temporary work. As we are particularly concerned here with only a few, it has been thought proper to deal with these separately.

Regulation 1*: All apparatus and conductors shall be sufficient in size and power for the work they are called upon to do and so constructed, installed, protected, worked and maintained as to prevent danger so far as is reasonably practicable.*

This Regulation is applicable to systems of all pressures, and places general responsibility upon the contractor for the safety and safe working of the installation. It requires not only that the apparatus and conductors must be so constructed and protected as to be suitable for the conditions under which they are required to operate, but also that they must be installed and maintained with due regard to safety.

The requirement that all apparatus and conductors shall be sufficient in size and power for the work they are called upon to do implies not only that they must be of adequate capacity for normal working, but that they should be capable of safely withstanding the electro-thermal and electro-magnetic effects of any short circuit which may occur.

The construction and installation must attain a suitable standard to be safe, and useful guides in this respect are the Regulations for the Electrical Equipment of Buildings, issued by the Institution of Electrical Engineers, and the specifications issued by the British Standards Institution, including those Codes of Practice which deal particularly with installation practice.

The rough usage to which certain apparatus is subjected in building operations and works of engineering construction necessitates the installation of apparatus having specially robust mechanical and electrical construction, and unless apparatus of this type is used under these conditions, efficient maintenance becomes impossible.

In confined spaces all conductors, no matter how low the pressure, should be protected.

Regulation 2*: All conductors shall either be covered with insulating material and further efficiently protected where necessary to prevent danger, or they shall be so placed and safeguarded as to prevent danger so far as is reasonably practicable.*

This Regulation applies to all conductors

whether insulated or not, but is of special importance as regards cables and wires. Where insulated cables are out of normal reach they are sometimes supported on insulated cleats without further protection. Before such an arrangement is adopted, however, consideration should be given to such operations as building repairs, installation or alteration of pipes for gas, steam or water services, and painting ; for in the conduct of these operations damage may be caused to the cables. Many accidents have occurred due to cables being damaged under such conditions, and cleated wiring should only be used where it is adequately protected by some feature of the structure, or by some other means. (Fig. 3.)

Flexible wires for portable apparatus, such as lamps, require to be heavily insulated and protected to withstand constant handling and rough usage. Flexible wires of the thin twisted type as used for pendant lamps are totally inadequate for this purpose.

Flexible cables with external wire armouring or metal braiding are not desirable, as the wires forming the protection tend to penetrate the insulation if they become broken or otherwise damaged. Where mechanical protection additional to that provided by a tough rubber sheath is required for any reason (such as the presence of highly inflammable circumstances) flexible armoured cables similar to those used as trailing cables in mines should be used.

In order to avoid deterioration of the rubber insulation of flexible cables connected to pendant lighting fittings due to the heat generated by the lamps, suitable ventilation of the fitting is necessary and, in the larger sizes, the cable should be of the heat-resisting type.

Cables at whatever pressure should be so arranged as to minimise fire risk and where such cables pass through floors or walls they should be enclosed by fire resisting material and all openings therein should be stopped.

Screw cap lampholders in which the screw portion of the holder and the lamp cap are conductors should be fitted with shrouds or skirts, or should be so placed and safeguarded in the lanterns that neither the lamp cap nor screw part of the holder can be touched when the cap is in engagement with the holder. Under certain conditions the lamp cap and screw part of the holder may be live and many fatalities have occurred as a neglect of this precaution[5].

Regulation 6 : *Every electrical joint and connection shall be of proper construction as regards conductivity, insulation, mechanical strength and protection.*

Every joint and connection should have at least the same properties in regard to conductivity, insulation, mechanical strength and protection as those of the system or circuit of which they form part. Joints formed by twisting together two conductors are not, therefore, permissible.

Special attention should be given to joints and connections in cables which have to be handled, as in flexible cables or for portable lamps. Such

Fig. 3. View showing 7/0.029 cable supplying portable 230-volt lamps lying on open mesh flooring over which barrow loads of cement, bricks, etc., were wheeled, thus causing damage to the cable insulation with the risk of electric shock to persons when they move the equipment as work progresses.

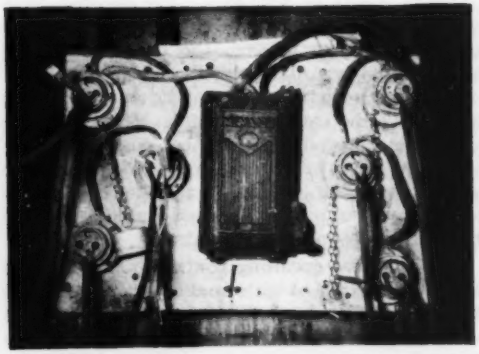


Fig. 4. Contractor's temporary plug board for giving supplies to hand lamps and tools seen in use recently on a building site. Note complete absence of 3-pin plugs; also the use of timber wedges to secure cables in some cases and the absence of any securing method in other cases.

equipment should be connected to the supply by means of sockets and plugs constructed in accordance with the relevant British Standards, and arranged so that earthing of the metal casing of the apparatus, where necessary, is automatically effected by the insertion of the plug. The use of a lampholder plug in combination with a lampholder does not constitute a satisfactory method of connection, in addition to failing to provide an automatic means of earthing the apparatus.

Regulation 13 : *Every flexible wire for portable apparatus . . . shall be connected to the system. . . . In all cases when a person handling portable apparatus . . . would be liable to get a shock . . . the metalwork must be efficiently earthed ; and any flexible metallic covering of the conductors shall be itself efficiently earthed. . . . A lampholder shall not be in metallic connection with . . . metallic work of a portable lamp.*

. . . Where the pressure exceeds low pressure the portable apparatus . . . shall be controlled by efficient means . . . capable of cutting off the pressure, and the metal work shall be efficiently earthed . . .

The requirements of this Regulation generally are that flexible wires for portable apparatus shall be connected to the circuit, whether permanently or temporarily, in a proper manner with properly constructed connectors. It is most important that there should be adequate protection of the flexible cable at the point of entry to the connector and an efficient cable grip. This is necessary to prevent danger from shock or burns due to short circuit where the cable enters the plug position and where insulation failure is most likely to occur. This is a common source of accidents. The flexible cable should enter the plug at the side where it need not (see Fig. 4) pass through the user's hand, and there should be a hand-shield, disc or other form of guard between the grip or handle and the portion containing the cable and contact pins. Contact with live pins should not be possible during insertion or withdrawal. Also, it should not be possible to insert one plug in a socket tube whilst the other pin or pins are exposed and may be alive through the connected apparatus.

The material enclosing contacts and terminals should be capable of withstanding any rough usage to which they may be subjected and this point should be borne in mind when selecting connectors for arduous service ; if of metal they should, of course, be earthed.

Satisfactory hand lamps should, as in the case of plug connectors, have efficient cable grips to relieve the strain on the conductors and terminals.

Under conditions such as those found on building operations and works of engineering construction, greatest safety is achieved by reducing the pressure as low as possible since in the event of a defect in the lampholder or its flexible cable, the danger of serious shock is almost eliminated, and the provision of transformers giving 12 or 25 volts on the secondary side cannot be too strongly advocated. There are many suitable portable transformers available for this purpose, and it is now possible for a transformer to be included in the connector which can plug directly into the existing mains supply circuits, stepping the 240 volts down to low voltages of 12/25/50 volts. There is then no danger from frayed leads, trailing cables, insulation breakdown, defective connections or wet floors ; the dangerous mains voltage stops at the connector.

The requirement that a lampholder shall not be in metallic connection with the guard or other metal work applies not only to single hand lamps, but also to portable lamp clusters.

Regulation 21 : *Where necessary to prevent danger adequate precautions shall be taken either by earthing or by other suitable means to prevent any metal other than the conductor from becoming electrically charged.*

This Regulation applies only at pressures exeeding 125 volts A.C. The metal work of all lighting fittings and shades must be earthed if the person engaged on cleaning them or removing a lamp is likely to be in contact with earth, as would be the case if he was standing on a wooden ladder but within reach of metal roof members.

Regulation 29 : *Instructions as to the treatment of persons suffering from electric shock shall be affixed in all premises where electrical energy is generated, transformed, or used above low pressure, or in such premises or classes of premises in which electrical energy is generated, transformed or used at low pressure as the Secretary of State may direct.*

This Regulation requires a notice to be posted giving instructions as to the treatment of persons suffering from electric shock.

It is of the greatest importance that in cases of electric shock artificial respiration be started at once and continued for at least an hour, preferably for two hours. Even if a medical practitioner states that life is extinct, artificial respiration should be continued as there are several cases on record where the victim's mates and co-workers have persisted in spite of such advice and have eventually succeeded in resuscitating him ; actual cases of recovery after 10 hours have been quoted.

The records of cases of electric shock in 1955 may be summarised as follows : of 60 persons

known to have been unconscious, five had fractured skulls or similar injuries, 15 of the remaining 55 received no artificial respiration and died, and of the remainder, who received attention, 19 recovered and 21 died.

In most cases where artificial respiration was applied it was started fairly promptly, though sometimes there were delays of five, 10 or 15 minutes. In one or two instances there was more delay, for example, when a man who had been welding in the double bottom of a ship was not found for some time. In other cases, there was inevitably some delay in moving the man before any first aid could be started, and it is possible that at least one or two of these men could have been saved if artificial respiration could have been applied promptly.

Artificial respiration was in most cases only continued for a short period. Ten persons recovered in less than five minutes, two after between five and 10 minutes, two in about 15 minutes, one in 20 minutes, and two in 30 minutes. In only six cases was artificial respiration continued for 20 to 30 minutes and in only one case for more than 30 minutes, but as in this instance there had been an hour's delay in starting, there cannot have been much hope.

All medical authorities are agreed that artificial respiration should be applied immediately, and that the chances of resuscitation, if commenced within a minute, have been placed as high as 95 per cent. of the cases.

Prolonged treatment on this scale makes it desirable to have apparatus available, and where this is not the case then manual methods must be started and maintained until the apparatus is forthcoming. Of all apparatus yet devised, the rocking stretcher is considered the most suitable. This consists of a tilting platform on which the patient is laid, on his back or face as is most suitable to the circumstances, and tilted to an angle of about 30 deg. up and down; the weight of his viscera acts as a piston compressing the lungs and also causes some massage of the heart.

It is now generally accepted that the Holger-Nielsen method of applying artificial respiration is the best that can be used manually, and it has been adopted by the Red Cross, Royal Society of St. John, and by the Electricity Boards, in place of the Schaefer method. It can be argued that if a man has internal injuries as well as electric shock, then any first aid treatment for shock will aggravate his injuries; the answer is, of course, that if he is not breathing he will die in any case so there is everything to be gained by making the attempt.

When an accident occurs it is too late to start reading instruction placards. Actual practice in the movements for half an hour, with a refresher course at quite rare intervals, perhaps once a year, will do more than any amount of reading to place personnel in the fortunate position of being able to give first aid to a comrade when the need arises.

(2.4) Woodworking Machinery Regulations[6]

There is only one of these Regulations which deals with artificial lighting, and this would apply at any building operation or work of engineering construction where there is wood-working machinery :—

Regulation 6 *: The means of artificial lighting for every wood-working machine shall be adequate and shall be so placed or shaded as to prevent direct rays of light from inpinging on the eyes of the operator while he is operating such machine.*

Where such machinery is being used or liable to be used at night it is important to shield any lamp in the vicinity of the operator which may produce glare on the worker or on the surface of the machine table whereby it could be reflected back into the eyes of the operator. Care should be taken to comply with these requirements, as any accident at a woodworking machine frequently results in permanent mutilation.

(2.5) Traffic Safety Code for Road Works[7]

A Code of Practice under the above heading has recently been issued as a White Paper and although not enforceable directly by law, can be used indirectly as requirements of the highway authority under Section 8 of the Public Utilities Street Works Act as amended by the Ninth Schedule to the Road Traffic Act, 1956.

Although the Safety Code is in two parts, we are only concerned here with certain sections of the first part dealing with lighting and guarding of obstructions at night; these can be briefly summarised as follows :—

(*a*) Obstructions shall be clearly marked by two or more red lights.

(*b*) The full width and length of the obstructions should be indicated by red lights continuously lit. Lamps are to be not exceeding 4 feet apart across the width and 12 feet along the length of the obstruction in towns, or with maximum spacing of 20 feet along the length outside town centres.

(*c*) Changes of direction necessary for any driver should be indicated by oblique lines of lamps supplemented by illuminated or reflector signs or

arrows (arrows to conform to Regulations and diagrams 142 or 143 of the Traffic Signs Regulations, 1957).

(*d*) Any red reflectors on barriers protecting obstructions should be in addition to, and not in substitution for, red warning lamps.

(*e*) There should be care and consultations to ensure that no confusion can arise with other lights and signs for rail, water or air traffic, and " night " is defined as the normal lighting-up time.

(*f*) Advance warning and warning signs should be clearly visible to approaching drivers by night as well as by day. Where head lamps are not normally used, signs should be illuminated.

(*g*) Attention is drawn to the Traffic Signs Regulations, 1957.

(*h*) Provisions must be made for advance warning signs where obstruction is not clearly visible, and suitable distances are recommended between these signs and the obstruction in varying conditions. The distances given are minima ; greater distances of, say, half as much again will normally be appropriate.

(*i*) Signs should give a clear warning of the danger ; they must be easily visible both by day and night, and be substantial and not easily blown or knocked over. Care should be taken that there is this provision when the signs are moved as the work progresses.

The danger of non-observance of an established Code such as this is that it may give rise to allegations of negligence. The Code has been published and must, for this reason if no other, be observed.

(3) Types of Lights and when used

Lighting can be divided into two main categories: permanent (or semi-permanent) and portable. The first category is usual for general lighting around the site and in completed parts of the operation, and the second, as the name implies, for temporary use. In either case, the conditions under which lights will be used are rough, and the greatest care must be taken to provide suitable protection for the conductors, especially where a cable passes round corners or through steelwork.

Wherever possible, it is considered essential that voltage should be reduced for all lighting purposes. There is a terrible risk with voltages at 230 volts A.C. and over, which disappears when there is a reduction below 125 volts A.C. It has been found that the most suitable arrangement is to provide conductors in circular tough rubber sheathing at 110 volts for the more permanent lights, and portable lamps on similar leads at 25 or 12½ volts.

There is always a tendency to use wiring in VIR for portable lights ; this protection is very vulnerable on any site and is quite unsuitable.

In addition to the flood-lighting previously mentioned, successful experiments have been carried out with a low voltage supply to cluster lights used in the loading and unloading of ships ; here the standard of light provided was quite adequate and was safe. A similar arrangement could be most satisfactorily used on building sites and works of engineering construction. (Fig. 5.)

There are many occasions when it is necessary to provide emergency lights and there should always be some provision made for this. There

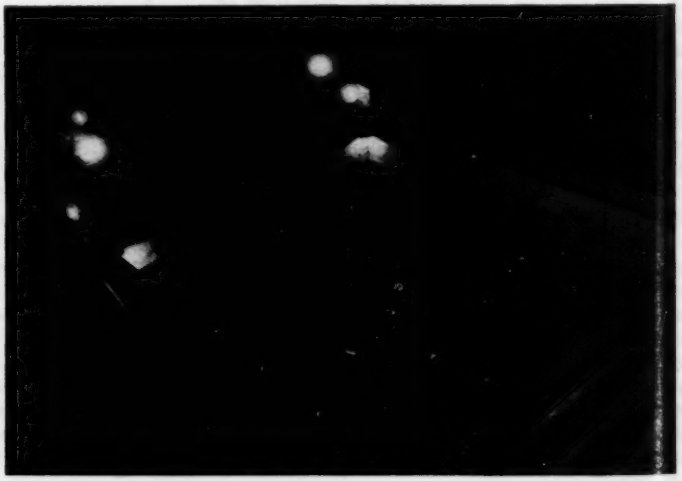


Fig. 5. Good example of high power low voltage lighting. Hold of collier showing at corner 300-watt 25-volt lamp, one of several supplied from a transformer on the dock side.

are several lighting sets available which can be used. One which has been found suitable on the railways consists of several powerful lamps secured to a swivel frame set up on a platform fitted to a wagon and powered from batteries, or from a petrol-driven generator. A set such as this has been of proved value in allowing work to be carried on continuously to clear the lines after a train accident.

On most building sites or engineering works there is always available a source of compressed air, and this can be used to operate a turbo-generator to produce power for several portable lamps during an emergency. Whilst these have been found useful on occasions, water tends to accumulate in the pressure pipe and cause breakdowns; the maintenance costs are, therefore, very high.

It has been reported from America that electric cap lamps of the kind usually associated with mines or work below ground are being used by workers in the construction of bridge superstructures where riveting and welding is done in dark confined spaces and conventional lighting systems cannot be used. Good illumination is essential. The use of dry cell batteries for the work would be neither practical nor economical as they are not dependable under such conditions and the light provided would not be adequate. In addition, failure of a lamp on a job offshore would cost the services of the man using it. It is usually impractical to use electric wiring on such a project because of the remote location of parts of the bridge structure plus the fact that the men are working in an area where the stringing of extension wires would create a footing hazard, and abrasive wear on wiring insulation could cause short circuits with possible resulting injury.

It has been found practical to use electric cap lamps powered by nickel-iron-alkaline batteries; the lamp headpiece fits on to a protective helmet normally supplied by the contractor, and this arrangement frees both hands of the workman, making his job safer and therefore more efficient. At the end of the working shift lamps are checked in at the contractor's office and placed in charging racks to assure the best possible illumination over the full shift.

What is commonly called "festoon" lighting with the use of "spike" type lampholders, has for some time been popular with many contractors because of its convenience; this has, however, been the cause of many accidents and is not suitable for use on sites. The "spike" connectors penetrate through the cable, allowing damp or wet to enter and cause shock. The punctures cannot, of course, be seen after the cable has been returned to store, and the cable is re-issued for use when quite unsuitable.

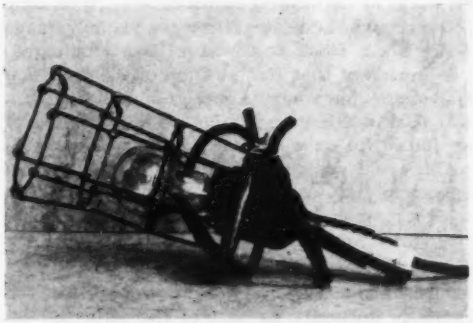


Fig. 6. Safety-type portable handlamp responsible for a fatal accident in a Lancashire boiler. The body of the handlamp was of wood and the lampholder was of metal into which was screwed a metal tube which passed inside the wooden handle. Owing to heat and moisture, part of the wooden handle split away from the remainder and the moisture made the metal lampholder and the tube alive. The lampholder was held by a man in such a position that the live metal tube made contact with his body and as he was sitting on one of the boiler fire tubes he received a fatal electric shock.

(4) Earthing

Since apparatus which is portable may be readily transferred to places where safe conditions do not exist, provision for earthing should always be made. The connection of the earth wire to portable apparatus should always be visible. There is an alternative to earthing in the case of certain portable apparatus, which has been extensively adopted for lampholders; this is one where the metal work is so covered with insulating material that it cannot be touched, then earthing becomes unnecessary. Lamps having guards of insulated material are preferable to those with metal guards. Hand lamps constructed of soft wood are quite useless in any situation since the wood is liable to split and will not withstand rough usage. (Fig. 6.) The not uncommon makeshift arrangement of a portable lamp at ordinary A.C. lighting pressures consisting of a non-earthed brass lampholder with lamp connected to a pair of flexible wires has been responsible for more fatal accidents than any other single piece of apparatus.

(5) Typical accidents

The lack of suitable lighting has been the cause of many serious accidents on building operations

and works of engineering construction. With only a little thought and care during the planning stage of the work, most would have been eliminated. It is important that the question of the provision of adequate temporary lighting should receive a great deal of attention during the initial stages of any job. Not only is there a legal obligation to provide good standards, but it is only too often dangerous not to. Many examples of such accidents are recorded in Government publications ([8]). A few typical examples are appropriate here :—

During the construction of a power station, the electricity authority as part of the terms of the contract to all the various contractors and sub-contractors, were responsible to provide lighting on the whole site. A firm A had excavated for foundations down to about 12 feet, and part of this excavation projected into one of the common access roadways. A barrier was erected around the opening at this point but was later removed by some person unknown. A contractor B had occasion to work overtime during the hours of darkness ; afterwards, one of his workmen was going home and was using this roadway, which he had a perfect right to do. He fell into the hole and was killed. The lighting at that part of the road was poor, and it was stated that the authority had been reminded on several occasions by both A and B of this. Nevertheless, although B had nothing whatsoever to do with the hole, the legal requirements are clear : there should be safe means of access to the place of work and the approaches should be adequately and suitably lighted.

At a siding where side tipping trucks discharged into a hopper opening at floor level, the lighting was such that during the hours of darkness this opening appeared to be a shadow, and a person walking by the side of the track fell into the opening and was smothered with coal.

The contractor on a building site provided a hurricane lamp for the use of the night watchman when doing his rounds during the hours of darkness. On one such tour of inspection he fell and broke his leg. The firm was prosecuted and fined. The Court held that a periodic inspection of the site was the regular thing for a night watchman to do, and he should have been provided with a suitable light ; the provision of a hurricane lamp for this purpose was not suitable.

Two men were washing out the interior of a boiler using a lighting fitting consisting of a truncated steel cone on which was mounted a brass lampholder into which was plugged an ordinary lamp for which there was no shield. The fitting was connected by means of a 3-core tough-rubber-sheathed cable to a 3-pin switch socket and thence to an A.C. 230-volt system. The men sat back to back across the bank of tubes with the fitting resting on the tubes between them ; as they began to spray water about, some fell on to the hot bulb, shattered the glass, and exposed the filament, which collapsed. In the dark, one of the men, attempting to get out of the boiler, came into contact with the live metal of the filament supports, sustaining a shock which proved fatal. The other man, although feeling a slight shock, managed to get out of the boiler, cut off the supply, and with great difficulty his mate was recovered from the boiler. The application of artificial respiration was too late.

During the demolition of tenements, the wiring from fuse boxes to the various flats had been made dead, but short lengths of VIR cable to the fuse boxes had not been made dead as the supply had not yet been disconnected ; a labourer pulled down the VIR cables and was killed.

Extension leads for temporary lights were left lying about while still live. These leads contained some twisted connections with black adhesive tape covering. A labourer was found lying dead on the wet ground with the cable under him ; the joint had been partly pulled out and the conductors were fully exposed.

The circumstances of all these accidents were such that, had there been a common-sense approach to the conditions under which the men concerned were to work—which would, of course, include the provision of adequate and suitable lighting and equipment—the accidents would have been prevented.

(6) Conclusions

It is well known that one of the greatest difficulties in accident prevention is to make persons employed think for themselves on this question of safety. Whilst the foreman or agent should be held strictly responsible for faulty equipment being available for use, the basic fault often lies in the lack of training and education in safety matters of both the supervisory staff and the workers. The former will see work being carried on in conditions which are dangerous, and because of their own lack of safety experience do not appreciate the danger ; whilst the latter who are, in many instances, of low intelligence, couldn't care anyway, their sole concern being the size of the pay packet at the end of the week.

There are records from 1556 describing building safeguards in mines to protect mine workers. In

the lists of mine accidents of that time there were comments such as " Often indeed the negligence of the foreman is to blame." It is true to say that now, 400 years later, the same complaint can be made and has been a factor in many serious accidents.

It is the general opinion among all who are concerned with industrial safety that it should not be left to a man's memory to do things in a safe way. Nor should it be considered sufficient to put up notices instructing him that he should do something in a certain manner. He may be tired, or careless, or even do things in a foolish way, or the notices may be blown down or defaced in some manner. There must be some mechanical safeguards, and in connection with the subject of this paper, the risks are generally those of electrocution, or hazards incurred due to faulty or inadequate lighting. The safeguards against these risks, whilst simple to express, are not always simple to put into operation.

First, the pressure on all sites should be reduced to below 110 volts, and second, as far as practicable, the necessary standards of lighting should be given real consideration during the design stage of any operation ; third, the equipment provided should be suitable for the work entailed ; there should never be the necessity for an improvised portable lamp, for instance. Fourth, the supervisory staff should receive adequate training and education to enable them to superintend the work without accident, and to show by example the safe way of working.

After all, as has been said many times before, a man who is injured and is off work is prevented from earning his normal wages ; this may result in much misery at home, where there may be many financial liabilities, and of course his job at the site stops for at least a time until other labour is available and trained to carry on where he left off at the time of the accident. In many instances this could be a serious matter for his employers.

Even though there has been much progress in the field of lighting and accident prevention on sites, there is still a great deal of room for improvement, and if there is nothing new about many of the points made above, there is also nothing new about the ways in which people get hurt, and many accidents would have been prevented had adequate lighting been provided.

The author is indebted to Mr. H. Midgley, M.Sc., M.I.E.E., of the Electricity Council, for permission to use some of the photographs illustrating the text.

References

(1) Factories Act, 1937—Sections 107(2) and 108(2).
(2) Building (Safety, Health & Welfare) Regulations, 1948 (S.I. 1948, No. 1145).
(3) Works of Engineering Construction : revised preliminary Draft of Regulations as to Safety, Health & Welfare in connection with such work. (1951.)
(4) Regulations for the generation, transformation, distribution and use of electrical energy in premises under the Factories & Workshops Act, 1901 to 1911 (S.R. & O. 1908, No. 1312).
(5) Precautions against danger in the use of Screw Cap Electric Lamps. (Form 1911 : H.M. Stationery Office.)
(6) Regulations for the Use of Woodworking Machinery (S.R. & O. 1922, No. 1196).
(7) Traffic Safety Code for Road Works—Ministry of Transport and Civil Aviation Memorandum No. 736.
(8) Electrical Accidents and their Causes (annual publication).
Annual Reports of H.M. Chief Inspector of Factories.

Discussion

Mr. D. SHORT : I am in charge of the Building & Civil Engineering Section of Her Majesty's Factory Inspectorate, and my job is to advise the trade on how to prevent accidents in building and civil engineering work. I would like to thank the Illuminating Engineering Society for having sponsored Mr. Scott's paper, and Mr. Scott, too, for having put the problem before you, because out of thousands of accidents reported to me every year some hundreds occur during darkness. Many are due to inadequate lighting, and could be avoided if lighting were improved.

Mr. Scott has shown by slides the causes of some accidents. There are two principles in accident prevention I would like you to keep in mind. The first is foresight—you must be able to visualise what is likely to happen in any particular set of circumstances. When you know that, then you can deal with the second, that is, the removal of the hazard. (Here Mr. Short showed three slides, one illustrating risks in the use of a hurricane lamp, the second showing a hazard caused by shadow falling across a hole in the floor, and the third illustrating the danger of brightness contrast.)

I would, however, like to take up Mr. Scott on some points which I think might have been mentioned in his paper. I know it is difficult to include everything, but these are important to the building and civil engineering trade. So far no one has produced a code of lighting standards—a standard which will achieve reasonably good lighting on the site. What type of lighting should you use ? How can you achieve the necessary difference between outdoor lighting and indoor lighting ? Effective outdoor lighting depends on silhouettes ; indoor lighting on detail. Could we

have a guide on illumination values for different types of site, e.g., for brick construction and for concrete construction? These values will be different. Could we also have the height of towers for lighting fittings so as to avoid glare, and the spacing of lighting fittings in order to achieve lighting values of say 0.5 or 1 lm/ft^2. Guidance is also needed on maintenance; you can lose 25 to 50 per cent. of illumination because of dirty fittings.

Section 5 of the Factory Act, which deals with lighting, does not apply to building sites, but it could well be used as a guide. Values of 2 lm/ft^2 are set for general lighting and 0.5 lm/ft^2 for passages at floor level.

I have to visit building sites all over the country, and I am afraid I find a lot of *ad hoc* and haphazard attempts at lighting. Not far from here is the new Shell building site which benefits from a lot of overspill lighting from streets, but the site lighting from towers with projectors seems based on no particular system.

I visited a nuclear power station a few days ago. Towers and projectors were used there but some were so low that glare was created at ground level. Other towers carried diffuser fittings to reduce the glare and any convenient crane was used as a mounting for projectors.

The use of the white coat for crane signalling is a good idea, but the load should also be illuminated, and there must also be good lighting at the picking-up point and where the load is being set down.

I would like to ask the I.E.S. to co-operate with the National Illumination Committee, the National Federation of Building Trades Employers, the National Federation of Civil Engineering contractors and the National Federation of Building Trade Operatives in order to collect information on lighting and draw up a guide for the use of the builders and civil engineers. They would be saved effort, material and cost. I am sure it is an object which the founders of the I.E.S. would have approved. (Here Mr. Short showed a slide of low-voltage lamps on a building site and one of a dockside showing overspill lighting, both providing very good standards.)

Mr. J. A. HAYWARD: As far as builders are concerned, the importance of good lighting is not yet generally realised. You saw a picture of the Leith Grain Silos job just shown you by Mr. Short. That picture was taken at midnight with an exposure of 1/25th second. It was taken on the first day of December, 1957, and at the same time as that picture was being taken, an accident occurred not more than 100 yards away on a ship where a member of the crew walked across a plank that was not there. There was a dark shadow across the hold, and the unfortunate man fell into the hold and was severely injured.

In my own company we have had some experience of lighting, good and bad. Mr. Scott mentioned an accident which occurred on a power station. It was my unpleasant duty to have to investigate that unfortunate accident. We have had others in my own company, but I like to think that we are getting towards the end of this wretched period in our industry, and despite some of the slides you have seen (which have a familiar look to me) such instances are getting less and less.

I was at Manchester only yesterday and saw an incident very similar to the one where Mr. Scott showed the cable on a runway with barrows going over it. In this case it was a lead for a crane and lorries and dumpers were going over it. When I tell you that it was on a site where buildings had only recently been demolished, you can get some idea of the conditions underfoot. The lead had been in this position a short time, the crane had been moved, but no one had taken the trouble to replace the lead. A small thing, which would not have taken five minutes to rectify, but which could have caused a serious accident.

I have found, particularly on ladder work where artificial light is being used, that it is useful to " blind " the surroundings with hessian so that you avoid shadows.

Mr. D. J. OLLIVER: As a building contractor I would like to say straight away that we are fully aware of our responsibilities as regards the safety of our workmen on our sites, and particularly aware of the dangers that have been brought about by the very great use of electrical power and lighting on contracts since the war.

We are, I am sure, only too hopeful that we will not have any accidents on our sites, and are willing to take every reasonable precaution to ensure they do not occur, but on the other hand there is the question of cost. The cost of temporary lighting, even though Mr. Scott said " just a cheap fitment," is very high. If you are going to light a building site where lighting is required only for a few hours, and you are going to light every little dark corner, then this is going to cost a lot of money.

As the regulations stand at the moment, we have to compete with smaller contractors who do not always comply with the regulations, and they are certainly not going to put in better lighting than the regulations require. One must rely on the

individual workman to use his common sense and not to remove protection boards over holes, but one cannot expect the whole site to be so well lit that there is no chance of a person falling down a hole.

The question of temporary lighting is a very considerable one and not only the amount of lighting, but the quality required to carry out different works on a building site. Plastering is carried out under artificial light, but I do not think the lighting is good enough for either safety or efficiency, and I think possibly the electrical industry could help contractors very considerably by investigating ways and means of producing a better quality of light at reasonable cost.

One of the problems since the war is the fact that although machines and temporary lighting and wiring are used by almost every workman on a building site, hardly any one of them knows anything about the dangers of electricity, and it is difficult to bring home the danger to them. I think possibly the publicising of these dangers would be a great help. Notices around the job are not enough; pictures of some kind might be a great advantage. Another thing we come up against is that they all think themselves amateur electricians and when a light gets knocked over and there is some damage, it is generally thought that a piece of insulation tape wrapped around is all that is required. You may lay down all sorts of rules and regulations that no installation is to be touched or repairs carried out except by an authorised person, but you cannot stop people doing it. These are very considerable problems, and I think we have to face up to the fact that our apparatus must be made as foolproof as possible.

The small electrical tools that have come into the industry are also a problem. Nearly every large building site today has, I would say, probably 50 or 60 small hand tools, saws, drills, grinders, etc., and these, again, are all used by people who do not realise what a lethal weapon they have in their hands. Men handling these small tools should use rubber boots; there may be some safety in that measure but it is not sufficient by any means, as these tools are trailed about the place and consequently you have high power cables lying around the site that can easily be broken. Voltages should be reduced to 110, but even so there is a very considerable danger.

Mr. S. J. Emerson: I should like to fill in a little detail on some of the points which have been raised by the author in regard to electrical installations on building operations. I agree on the degree of safety achieved by reduction of voltage to 110, the important point being that, with mid-point earthed, the shock voltage to earth is kept down to 55 volts—a comparatively safe figure.

The author showed us a lantern slide of a deplorable improvised plug distribution board, of which I am glad to say there are very few, if any, in use today; I have not actually seen anything quite so bad.

What really matters most on a building site is the efficiency of the main earth connection. Often the mains supply for the site is derived from a small transformer, sometimes mounted on a pole. To drive in an earth spike at the foot of the pole on a wet day and go away content is to invite disaster; a dry spell follows, the earth resistance rises to a dangerously high figure, and the spike is useless. Perhaps the best use for such a spike is for the radio earth (not the safety earth) of a radio set. From my own experience over many years, the majority of fatal accidents have some such background. The remedy is to make an effective earth and to run back a solid earth conductor to the metal tank of the transformer. Where the supply is taken from a medium-voltage distribution system and there is no transformer, the supply authority usually permit the solid conductor to be bonded to the sheath and armour of their service cable. Wherever this is possible, I commend it to you.

Controlled maintenance of all electrical equipment on the site is of the utmost importance, particularly of hand tools, which should be regularly and frequently tested. To ensure that no individual tools are overlooked, it is important that the tests should be under control and not haphazard, and that records should be kept so that any gradual deterioration may be detected in its early stages and rectified.

On the prickly question of "Blackpool" festoon lighting, I agree generally with the author, but as a point of interest I looked in on several building sites on my way here tonight, and on every one festoon lighting was in use. To say bluntly that this must not be used is, in my view, not quite the most practicable approach; rather let us adopt the type of festoon lighting which incorporates moulded lampholders as an integral part of the cable and avoids damage by spikes which penetrate the outer protective covering and the insulation. What can happen with the spike variety is shown by a recent fatal accident on a site near London Bridge. A painter who had been using for general lighting festoon cable energised at 50 volts, took a length of dismantled

cable and used it with a portable handlamp at mains voltage in a damp and exposed position. He was electrocuted while handling the punctured cable.

The maintenance of cables is indeed a real problem for the contractor, and I have found that the solution is the use of heavy-duty T.R.S. cable further protected where necessary by stout rubber or canvas hose, such as they usually have available with the air compressors; if also you replace metal plugs and sockets by heavy-duty tough rubber ones, you will have made good use of the improved materials and accessories now available.

Finally, I must refer to the author's extract from Regulation 13, and point out that he has actually omitted certain words which are very helpful—namely that direct-current apparatus at a voltage not exceeding 150 volts is not required to be earthed. To take advantage of this, all that is necessary is to use a transportable rectifier unit, and several contractors who have introduced this method tell me that they are very satisfied. Incidentally, they get better operation with universal tools when they are working on direct-current and the overall cost is no greater than with the conventional low-voltage transformer.

Mr. F. C. SMITH: I served recently on a Sub-Committee appointed by the British Medical Association, which in the course of its work was concerned with rescue work involving artificial respiration. I would like to underline some of the observations made by the author in this connection.

It appears generally agreed that the Holger Neilson method of artificial respiration is to be preferred to those previously used since, while it is equally effective, it involves less physical effort on the part of those carrying out the treatment, and thus it can be continued for longer periods with less physical fatigue. An additional advantage over other methods is that there is no possibility of using undue pressure, and causing bruising or other more serious injury to the patient. I stress the author's advice that artificial respiration should be continued, notwithstanding the absence of any apparent indication of response by the patient, until there is no possible doubt that life is extinct.

I wish to make a further point. Cases have been brought to my notice in which artificial respiration has been in progress at the site of the accident with promising results but normal respiration has not been fully re-established when the ambulance arrived. In a very understandable desire to get the patient to hospital without delay, artificial respiration has been discontinued and during the journey to the hospital a relapse occurred and the patient has died. A case occurred recently in which two children were involved; both received artificial respiration and "came round." They were put into an ambulance but there was only one man in attendance during the journey. Both children suffered a relapse, and one died because it was not possible for the one man to attend to both, especially under the conditions which obtain in the "two shelf" type of vehicle. Do not allow casualties to be rushed to hospital in ambulances if this involves the discontinuation of artificial respiration before the patient is ready to be moved.

THE AUTHOR (in reply): I have listened most carefully to the discussion which has followed my paper, and I was a little disappointed that opportunity had not been given for discussion on the primary topic of illumination and the resulting hazards to persons employed when this is not satisfactory. It appeared that several of my points have been elaborated and indeed illustrated by some excellent slides, but in the main, I received the impression that the discussion revolved around the general use of electrical power on building sites and works of engineering construction.

The suggestion from Mr. Short that the I.E.S. should promote a committee to study the problem of providing adequate illumination on sites cannot in my opinion be too strongly advocated. I am quite certain that the time has come when it is essential that there should be an authoritative guide as to the minimum standards of lighting on sites. The Society would be doing a real service if they were to institute such proceedings, and I know there are several persons present tonight who are well qualified to give much helpful information to any committee which may be formed to study this question.

With regard to Mr. Emerson's point on controlled maintenance, I agree entirely that this is of the utmost importance, and only with a well-defined system which ensures adequate testing, before any issue, of portable equipment, can we be certain that something positive is being done to prevent unnecessary accidents.

There is, of course, always a risk with the use of electrical equipment, a risk which virtually disappears when the voltage is reduced below 110. As most of the manufacturers have an export connection with North America, where the standard voltage is 110, there is no difficulty in obtaining similar equipment for use here, in conjunction with suitable transformers.

UDC 628.93

Lighting Design—The Next Step

Contributed by the Lighting Design Data Panel of the I.E.S. Technical Committee

One of the first actions of the I.E.S. Technical Committee was to set up a Panel with terms of reference including the following: To examine the past and more recent work on methods for calculating Coefficient of Utilisation values and make recommendations.

The Panel has been engaged for some time on this task and has presented an Interim Report to the Technical Committee in which are made certain proposals affecting lighting design data and calculation. This contribution is submitted by the L.D.D. Panel with the approval of the Technical Committee as a means of explaining to the Society the Panel's proposals while at the same time referring briefly to certain recent developments in lighting design with which the proposals are linked.

Signed: W. Robinson (*Chairman*)
A. D. S. Atkinson
H. E. Bellchambers
R. R. Holmes
W. Imrie-Smith
J. M. Waldram

Introduction

Lighting calculations for interiors have for many years been largely confined to finding the average illumination on a working plane, calculated using Coefficients of Utilisation. For some years it has been evident that methods of design should go much further, to include design of luminance patterns and other factors (e.g. glare), thus eventually achieving a design of the visual field. It has also been evident that the present Coefficient of Utilisation data are incomplete and in some respects inaccurate, and that the system is due for revision.

The L.D.D. Panel was asked to investigate methods of design for illumination and to make recommendations. It has, in fact, recommended a method which provides a more logical and precise system of finding Coefficients of Utilisation. This method has the further advantage that it can be linked with methods of luminance design now being developed, so that in pursuing this method there is the possibility of making further progress.

The method recommended is the Zonal method produced by J. R. Jones and J. J. Neidhart of the United States. The case for adopting this method is discussed below; the method is described and sufficient data are given to enable those interested to acquaint themselves with its use.

The Case for Adopting the Zonal Method

From its first meeting the Panel has kept constantly before it the question of whether such a change is justified. Its members are fully conscious of the importance of the step which it proposes, and in particular of the problems which it will raise both within the lighting industry and with members of the Society. It is important, therefore, that the case for it be thoroughly argued, for it would obviously be better to leave matters as they are than to attempt such a change without full support, particularly from the manufacturers of lighting equipment on whose co-operation the effectiveness of the method depends.

The present situation in lighting design is not a happy one. On one side are practising lighting engineers using data which have ceased to be appropriate to much of the equipment now used and which as a result are often so much interpolated or extrapolated as to represent little more than a guide to the final result. On the other side are investigators and mathematicians both contributing to a great, and mostly unused, store of knowledge concerning the application of luminance and luminosity concepts. While these groups go their separate ways there is a growing sense of the scope for improvement in the use of lighting, and of the need for greater liaison between lighting engineers, architects and artistic consultants.

There is good reason to believe that the introduction of better data, and of better design techniques, through a method which nevertheless lends itself to commercial design practice, will go far to bridge the gap between those in the field and those in the back room.

The question will inevitably be asked, however, whether it is worth while merely to change from one set of illumination design data to another set, when, in fact, the concept of working plane illumination is itself in question as a sole design aim. The answer is that the form of luminaire flux distribution specification on which the Zonal method is based happens to be just that which is

needed for luminance design. Furthermore the breakdown of the data into direct and inter-reflected components makes them immediately usable for the purpose of predetermining luminances. Of equal importance is the fact that the data are mathematically derived and free from experimental error, other than that arising out of photometry of the luminaire. Within the scope of their application, i.e. axially symmetrical luminaires, they cover all possible luminaire flux distributions.

The Panel is fully conscious of the errors and uncertainties which arise in the practical application of lighting data, due to the difficulties of precisely estimating reflectance and maintenance factors, the effect of variation in voltage on lamp output and other causes. The view has been expressed that the existence of so may chances of practical error nullify the benefit to be obtained from more accurate basic data. The Panel disagrees with this viewpoint for the following reasons. Practical errors may augment, or may tend to cancel out, whatever errors there may be in the basic data, but the degree of error possible is directly related to the degree of error of the basic data. Hence the effect of reducing error in the basic data is to reduce the possible total error. Furthermore, it lays the foundation for still further improvements in accuracy such as will arise from increased uniformity Of lamp performance, and increased knowledge concerning other factors, e.g. depreciation, reflectance, etc.

Terminology

The matter of terminology has posed a problem to the Panel for a choice has had to be made between the terminology used in the American report on the Jones-Neidhart Zonal Method, or terminology which conforms to international practice.

The Panel has, in fact, used in this contribution the same terminology as is used in the American report so as to avoid possible confusion in the minds of those wishing to refer to this report, or to previous papers of Jones and Neidhart. It is recognised, however, that it is desirable ultimately to reconcile the terminology with international practice.

The following are the terms and definitions used in this contribution :—

Direct Ratios and Ceiling Ratios express the light distribution of luminaires in terms of the light flux from them which is directly incident on the work plane and ceiling respectively.

Downward, or Upward, Light Output Ratio.

The proportion of downward, or upward, flux emitted from the luminaire to the total flux emitted from the light source.

Downward Utilization Factor.

The proportion of the downward flux from the *luminaires* which reaches the work plane. This is the sum of the Direct Ratio and the proportion of downward luminaire flux which reaches the work plane after interreflection.

Upward Utilisation Factor.

The proportion of the upward flux from the *luminaires* which reaches the work plane.

Downward Coefficient.

The proportion of the downward flux from the *lamps* which reaches the work plane. This is given by : Downward Utilisation Factor x Downward Light Output Ratio.

Upward Coefficient.

The proportion of the upward flux from the *lamps* which reaches the work plane. This is given by : Upward Utilisation Factor x Upward Light Output Ratio.

The Coefficient of Utilisation is the ratio of the total luminous flux reaching the work plane to the total light source flux and, in the Zonal method, is the sum of the Downward and Upward Coefficients.

The Basis of the Zonal Method

The Zonal method considers the illumination in an interior as resulting from two components :—

(1) The Luminaire flux reaching reference surfaces directly (i.e., without reflection).

(2) The Luminaire flux reaching the horizontal reference plane indirectly (i.e., after reflection).

The proportion of total downward luminaire flux from a symmetrical luminaire layout which arrives directly at the working plane is known as the Direct Ratio, and similarly the proportion of total upward luminaire flux which arrives directly at the ceiling is known as the Ceiling Ratio. Direct and Ceiling Ratios, it should be noted, are characteristics of luminaires forming part of a symmetrical lighting layout in a room of given shape.

The method used to obtain the Direct Ratio is as follows :—

For each luminaire location (in a symmetrical layout and with a given spacing/height ratio in a square room representing a range of room indices, the percentage of lumens in each 10 deg. zone which strike the work plane directly has been calculated. (See Fig. 1.) By averaging the

p rcentage in a given zone for all luminaires an a erage for that zone has been obtained. These a erage figures, called Zonal multipliers, have b en tabulated for the present range of Room I dices and for a range of spacing/height ratios f m 0.4 to 1.5. (Appendix 1 gives these for the l ter ratio.) *These Zonal multipliers are dependent o ly on the geometry of the room and on the luminaire l yout.*

For each downward 10 deg. zone (0–90 deg.) the product of the flux in that zone and the corresponding zonal multiplier are found and these are summed to give the total luminaire flux directly incident on the work plane. This, divided by the total downward lumens of the luminaire, gives its Direct Ratio for the specific room ratio and spacing/height ratio.

Ceiling Ratios are similarly obtained but due to the relative closeness of luminaires to the ceiling the effect of variations in spacing/height ratio is significant only in the case of totally indirect lighting.

Some of the downward luminaire flux will reach the work plane only after reflection or interreflection; for any Direct Ratio, room index and room reflectances the combined effect of the direct and interreflected flux is obtained directly from an appropriate table giving the Downward Utilisation Factor. This is then multiplied by the Downward Light Output Ratio of the luminaire to give the Downward Coefficient.

The Upward Coefficient for the appropriate Ceiling Ratio is similarly obtained from another table and the Coefficient of Utilisation is the sum of the Downward and Upward Coefficients.

Procedure for Determining Coefficients of Utilisation

Typical data tables are given in Appendix 2; Appendix 3 contains some typical luminaire data, i.e., Light Output Ratios, Direct and Ceiling Ratios. The procedure for calculating Coefficients of Utilisation using this data is then as follows:—

(1) Work out Room Index, $\frac{lw}{(w + l)\,h}$, where h = height of luminaire above the work plane.

(2) Read off from the appropriate table the Downward Utilisation Factor appropriate to the Room Index, and to the Direct Ratio of the luminaire to be used.

(3) Multiply the D.U.F. by the Downward Light Output Ratio of the luminaire. This is the Downward Coefficient, and is also the Coefficient of Utilisation if the luminaire has no upward light component.

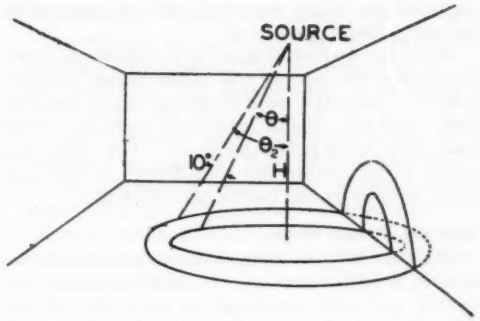


Fig. 1. The flux in any zone that strikes the work plane directly is equal to the total lumens in the zone minus the lumens that strike the wall.

(4) Similarly apply the Ceiling Ratio of the luminaire to the appropriate table to find the Upward Utilisation Factor or, in the case of ceiling mounted luminaires, read off the U.U.F. directly from Table 5.

(5) Multiply the U.U.F. by the Upward Light Output Ratio to obtain the Upward Coefficient. (This is also the Coefficient of Utilisation for Indirect Luminaires.)

(6) Add the Downward and Upward Coefficients to obtain the Coefficient of Utilisation.

Notes on the Application of the Data

The data are mathematically derived and there is no reason to question their accuracy. They apply to axially symmetrical luminaires and two conventions have been used in compiling them:—

(1) That suspended luminaires are at two-thirds the height between the ceiling and the work plane.

(2) That the luminaire layout is symmetrical, the distance between outer luminaires and the wall being half the luminaire to luminaire spacing.

These two conventions apply to the present Harrison-Anderson data, a fact which is not generally realised. The first convention has to be adapted in order that the direct and interreflected components can be dealt with by use of the one room index, $\frac{lw}{(w + l)\,h}$, where h = height of luminaires above the working plane. The effect of suspensions differing from this has not been determined by the Panel but there is good reason to be confident that serious errors will not arise in normal practice.

Luminaires within 12 in. of the ceiling are

regarded as ceiling mounted and are separately treated. (See Appendix 2.)

When the method is applied to layouts in which luminaires are not at the conventional distance from the walls the main error will occur near the walls and the overall error will increase as the numerical room index decreases. The Panel has under consideration the possibility of applying some form of correction for this condition.

Spacing/Height Ratio

The Direct Ratio of luminaires is linked with the spacing/height ratio and complete accuracy involves an initial estimate of it. This is not difficult, and the fact that a recalculation may have to be made following a bad initial estimation is a penalty which precision demands. Small variations between estimated and final spacing/height ratio will not seriously affect the accuracy of the result.

Proposals of the L.D.D. Panel for the application of the Zonal Method

(1) *Range of Reflectances*

It is recommended that the following range of reflectances be adopted for the basic data:

Ceiling	*Walls*	*Floor*
per cent.	per cent.	per cent.
70	50 30 10 0	10 30
50	50 30 10 0	10 30
30	30 10 0	10 30

Note: The zero wall reflectance data will be particularly useful in the case of installations covering part only of an interior.

(2) *Room Index*

The expression for room index, $\frac{lw}{(l + w)\ h}$ is the same as that used by Harrison and Anderson and it is therefore possible to use the numerical index in place of the letter index now used. It is recommended that numerical room indices be used, in place of the existing letter indices because:—

(*a*) They obviate the necessity for Room Index tables.

(*b*) They permit interpolation in the data tables giving greater accuracy.

(3) *Direct and Ceiling Ratios*

It is recommended that the co-operation of manufacturers be sought in making available Direct and Ceiling Ratios for luminaires to which they are appropriate.

(4) *Light Output Ratio*

It is essential for the working of the Zonal method that the upward and downward light output ratios of luminaires should be separately known. The Panel therefore recommends that Luminaire Light Output Ratios be given for the upper and lower hemispheres separately.

(5) *Standard Presentation of Luminaire Data*

It is clearly advisable to standardise from the outset the form in which this data will be presented. Direct Ratios will obviously only be given for spacing ratios within the maximum recommended by the manufacturer; for concentrating reflectors they may be given only for, say, 0.4 and unity spacing ratio; for dispersive reflectors and general diffusing luminaires they may be given for spacing ratios of 0.4, 1.0 and 1.5. Clearly discretion lies with the manufacturer on this point.*

At the foot of the page a suggested form of presentation of standard luminaire data is given, being data for a typical general diffusing luminaire at a spacing height ratio of 1 : 1.

(6) *Tabular Presentation of Utilisation Factors*

The Panel proposes that Upward and Downward Utilisation Factors be presented in the form of tables combining the Direct or Ceiling Ratios with their associated Downward or Upward Reflected components so that the factors are read off directly in a manner similar to the present procedure for reading off Coefficients of Utilisation. (See Appendix 2.) It is considered sufficient that the data be given to the second significant decimal place.

(7) *Zonal Multipliers*

It is proposed that, for the convenience of manufacturers and others wishing to evaluate Direct and Ceiling Ratios, complete sets of Zonal

*The effect of the spacing/height ratio on the Direct Ratio is receiving study; the Panel expects to be able to offer more detailed guidance in due course.

Light Output Ratios.

UP 0.39

$s/h = 1$

DOWN 0.45

TOTAL 0.84

ROOM INDEX	0.6	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
DIRECT RATIO	.16	.23	.28	.33	.38	.46	.52	.56	.63	.68
CEILING RATIO	.25	.32	.39	.45	.50	.58	.65	.71	.77	.81

Multipliers be made available by the Society. A typical worksheet for calculating Direct Ratios, including Zonal Multipliers for $1\frac{1}{2}:1$ spacing/height ratio is given in Appendix 1.

The Importance of the Manufacturers' Contribution

The Zonal method is dependent on the availability of standard luminaire data, i.e., Direct and Ceiling Ratios, and Upper and Lower Light Output Ratios. Direct and Ceiling Ratios can be calculated from polar curves but the Zonal method could hardly hope to gain general acceptance if this procedure had to be gone through for each type of luminaire encountered by each designer. A particularly valuable feature of Direct and Ceiling Ratios is that they facilitate the estimation of the light flux directed to floor, ceiling and walls in a given situation. Moreover the point has already been reached where the major design objective is an installation giving the direct luminaire flux on work plane, ceiling and walls required to produce a specified luminance pattern. This is involved in J. M. Waldram's Designed Appearance Method, and the ready availability of standard luminaire data as proposed by the Panel would bring this technique within the compass of the commercial engineer. If polar curves or 10 deg. zonal flux data only were available, this method would require the application of trial and error in the search for the right luminaire.

It is with all these considerations in mind that the Panel has suggested inviting the co-operation of manufacturers, particularly as no extra photometry is involved.

The Panel is unanimous in its view that the most important feature of its proposals is that they necessitate, and rest on, this comprehensive specification of the light output ratio and the light distribution of luminaires. Without this it is futile to seek for improvement in either design data or technique, and without the co-operation of the luminaire manufacturers in making such information readily available it is equally futile to attempt to translate the achievements of research into day-to-day lighting practice.

Luminance Design and the Zonal Method

The Terms of Reference of the Panel were originally confined to the examination of data and methods for determining Coefficients of Utilisation. In the course of its work it has become apparent, both to the Panel and to the Technical Committee, that the establishment of the Zonal design method could become a decisive factor in the general adoption of luminance as the ultimate design objective. The reason for this is the great simplification which would be made in luminance design by the availability of standard luminaire data. (See Appendix 3.) The full implications of this are not dealt with here but there can be no doubt that the general adoption of luminance design methods will be facilitated by increasing familiarity with this method of illumination design.

Although the L.D.D. Panel regards the Zonal method of design in the form recommended as a bridge between the present and the future of lighting design technique, it nevertheless wishes to make clear that its immediate purpose, namely to provide a more accurate and flexible basis for the determination of Coefficients of Utilisation, is ample justification for its general adoption now.

Appreciation

The authors wish to acknowledge their debt to many workers whose contribution to the improvement of lighting design techniques could not be individually acknowledged. They wish particularly to record their appreciation of the work of J. R. Jones and J. J. Neidhart which is the basis of the Panel's proposals.

Bibliography

Harrison Ward, and Anderson, E. A. "Coefficients of Utilisation," Trans. I.E.S. (U.S.A.), **15**, 97 (1920).

Jones, J. R. and Neidhart, John J., "Coefficients of Utilisation for Luminaires with Concentrating Distribution." Illuminating Engineering, **46**, 601 (1951).

Jones, J. R. and Neidhart, John J., "The Zonal Method of Computing Coefficients and Illumination on Room Surfaces," Illuminating Engineering, **43**, 949 (1948).

"Calculating Coefficients of Utilisation" (A Report of the Committee on Lighting Design Practice of the Illuminating Engineering Society), Illuminating Engineering, **51**, 385 (1956).

Appendix 1

Worksheet for computing Direct Ratios

Spacing Ratio = 1.5 : 1

Luminaire Description.....

Zone (deg.)	Room Ratio	0.6		0.8		1.0		1.25		1.5		2		2.5		3		4		5	
	Luminaire Flux (lumens)	Zonal Multipliers. 0–90 deg. (for Spacing Ratio 1.5 : 1)																			
0–10		1.0		1.0		1.0		1.0		1.0		1.0		1 0		1.0		1.0		1.0	
10–20		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0	
20–30		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0		1.0	
30–40		.32		.86		.88		.91		.92		.94		.95		.96		.97		.97	
40–50				.26		.33		.45		.54		.65		.72		.77		.83		.85	
50–60				.22		.29		.35		.42		.55		.63		.69		.77		.80	
60–70				.02		.09		.17		.24		.37		.48		.56		.67		.71	
70–80												.06		.15		.25		.41		.51	
80–90																		.02		.04	
TOTAL																					
Direct Ratio																					

Procedure for computing Direct Ratios.

(1) From luminaire polar curve (or other data) enter luminaire flux output in each 10 deg. zone.

For each Room Index:

(2) Multiply luminaire flux in each zone by the Zonal Multiplier and enter the product in the adjacent space.

(3) Sum the products and divide by the total luminaire flux to obtain the Direct Ratio.

Appendix 2

Tabular Data for the Zonal Method

The full data presentation takes the form of Tables covering two basic luminaire classifications, i.e. ceiling mounted or suspended. All luminaires mounted within 1 ft. of the ceiling are treated as ceiling mounted ; all others are treated as suspended. The complete data is contained in

10 Tables as follows :—

For suspended luminaires :—

(1) 70 per cent. Ceiling
  (a) Downward Utilisation Factors.
  (b) Upward Utilisation Factors.

(2) 50 per cent. Ceiling
  (a) Downward Utilisation Factors.
  (b) Upward Utilisation Factors.

(3) 30 per cent. Ceiling
  (a) Downward Utilisation Factors.
  (b) Upward Utilisation Factors.

For ceiling mounted luminaires :—

Tables giving Downward Utilisation Factors—

(4) (a) 70 per cent. Ceiling
  (b) 50 per cent. Ceiling.
  (c) 30 per cent. Ceiling.

(5) One Table giving Upward Utilisation Factors applicable to all ceiling mounted luminaires.

Each table gives data for 10 or 30 per cent. floor reflectance, 50, 30, 10 and zero per cent. wall reflectance. The data for 30 per cent. floor reflectance is given in the form of an additive correction table to the main table covering 10 per cent. floor reflectance. This form of presentation is not only convenient for publication but has the merit of showing at a glance the effect of floor reflectance in any situation. Since the assessment of floor (or work plane) reflectance is always uncertain it is very helpful to have alongside each other comparative data for two normal limiting cases.

Tables 1 (a) and (b), 4 (a) and 5 are reproduced on pp. 108-111 as indicative of the form taken and to allow readers to familiarise themselves with their use in conjunction with Appendix 3 (p. 112) in which typical standard data is given for a few well-known types of luminaire.

This contribution by the Lighting Design Data Panel of the Technical Committee will be discussed at a meeting of the Society to be held in London later in the year.

Specimen Table 1 (a)

Downward Utilisation Factor—Suspended Luminaire (Ceiling R.F. 70 per cent. Floor R.F. 10 per cent.)												Additive Correction for 30 per cent. Floor R.F.									
Room Ratio	Wall R.F. per cent.	Direct Ratio										Direct Ratio									
		.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0.6	50	22	32	41	49	58	67	76	84	93	1.01	1	1	1	2	2	2	2	2	2	3
	30	16	25	35	44	54	63	73	82	91	1.00	0	1	1	1	1	1	1	1	1	2
	10	12	22	31	41	51	61	71	81	90	1.00	0	0	0	0	0	0	0	0	1	1
	0	11	20	30	40	50	60	70	80	90	1.00	0	0	0	0	0	0	0	0	0	0
0.8	50	25	34	43	52	60	69	77	85	93	1.01		1	1	2	2	2	2	3	3	4
	30	17	27	36	46	55	64	73	83	92	1.01		0	1	1	1	1	1	1	1	2
	10	12	22	32	42	51	61	71	81	90	1.00		0	0	0	1	1	1	1	1	1
	0	11	20	30	40	50	60	70	80	90	1.00		0	0	0	0	0	0	0	0	0
1.0	50		36	45	53	62	70	78	86	94	1.02		1	1	2	2	3	3	3	4	4
	30		28	38	47	56	65	74	83	92	1.01		1	1	1	1	1	2	2	2	2
	10		22	32	42	52	62	71	81	91	1.01		0	0	0	1	1	1	1	1	1
	0		20	30	40	50	60	70	81	91	1.01		0	0	0	0	0	0	0	0	0
1.25	50			47	55	64	72	80	87	95	1.02			1	2	2	3	3	4	4	5
	30			39	48	57	66	75	84	93	1.01			1	1	1	2	2	2	2	3
	10			32	42	52	62	72	81	91	1.01			1	1	1	1	1	2	2	2
	0			30	40	51	61	71	81	91	1.01			0	0	0	0	0	0	0	0
1.5	50			48	57	65	73	80	88	95	1.03			2	3	3	4	4	5	5	6
	30			39	49	58	67	76	85	93	1.02			1	1	2	2	2	2	3	4
	10			33	43	53	62	72	82	92	1.01			1	1	1	1	1	2	2	2
	0			30	41	51	61	71	81	91	1.01			0	0	0	0	0	1	1	1
2.0	50			50	58	67	75	82	90	97	1.04			3	4	4	5	6	6	6	7
	30			41	50	59	68	77	86	94	1.03			2	2	2	3	3	4	4	5
	10			33	43	53	63	73	83	92	1.02			2	2	2	2	2	2	2	3
	0			30	41	51	62	72	82	92	1.02			0	0	0	1	1	1	1	1
2.5	50				60	68	76	83	90	97	1.04				5	5	6	7	8	8	9
	30				51	60	69	78	86	95	1.03				3	3	4	4	5	5	7
	10				44	54	63	73	83	93	1.02				1	2	2	3	3	4	5
	0				42	52	62	72	82	92	1.02				0	0	1	1	2	3	3
3.0	50				61	69	78	84	91	98	1.04				5	6	6	7	8	9	10
	30				52	61	70	78	87	95	1.03				4	4	4	5	6	7	8
	10				44	54	64	74	83	93	1.03				2	3	3	4	4	5	5
	0				42	52	62	73	83	93	1.03				1	1	1	1	2	3	4
4.0	50					70	78	85	92	99	1.05					7	8	9	10	11	12
	30					62	71	79	88	96	1.04					5	6	7	7	8	10
	10					55	65	74	84	94	1.04					3	4	5	6	6	7
	0					52	62	73	83	93	1.04					2	3	3	4	5	6
5.0	50						78	85	92	99	1.06						9	10	11	12	12
	30						71	80	88	97	1.05						7	8	9	9	11
	10						65	75	85	94	1.04						5	6	7	8	9
	0						62	73	83	93	1.04						4	5	6	7	

Specimen Table 1 (b)

Room Ratio	Wall R.F. per cent.	Upward Utilisation Factors—Suspended Luminaires (Ceiling R.F. 70 per cent. Floor R.F. 10 per cent.) Ceiling Ratio											Additive Correction for 30 per cent. Floor R.F. Ceiling Ratio										
		0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0.6	50	13	13	14	14	14	15	15	15	16	16	16	0	0	0	0	0	0	0	0	0	0	0
	30	06	07	07	08	08	09	09	10	11	11	12	0	0	0	0	0	0	0	0	0	0	0
	10	02	02	03	04	05	05	06	07	07	08	09	0	0	0	0	0	0	0	0	0	0	0
	0	00	01	02	03	04	04	05	05	06	07	08	0	0	0	0	0	0	0	0	0	0	0
0.8	50	16	17	17	18	19	20	21	22	22	23	24	0	0	0	0	0	0	0	0	0	0	0
	30	08	09	10	11	12	13	14	15	16	17	18	0	0	0	0	0	0	0	0	0	0	0
	10	02	03	04	06	07	08	09	11	12	13	14	0	0	0	0	0	0	0	0	0	0	0
	0	00	01	03	04	05	07	08	09	11	12	13	0	0	0	0	0	0	0	0	0	0	0
1.0	50	18	20	21	22	23	24	25	26	28	29	30	0	0	0	0	0	0	0	0	0	0	0
	30	09	11	12	14	15	17	18	20	21	23	24	0	0	0	0	0	0	0	0	0	0	0
	10	03	04	06	08	09	11	13	15	16	18	20	0	0	0	0	0	0	0	0	0	0	0
	0	00	02	04	06	07	09	11	13	15	16	18	0	0	0	0	0	0	0	0	0	0	0
1.25	50	22	23	25	26	28	29	30	32	33	35	36	0	0	0	0	0	1	1	1	1	1	1
	30	11	13	15	17	19	20	22	24	26	28	30	0	0	0	0	0	0	0	0	0	0	0
	10	03	05	08	10	12	14	17	19	21	23	25	0	0	0	0	0	0	0	0	0	0	0
	0	00	02	05	07	09	12	15	17	19	21	23	0	0	0	0	0	0	0	0	0	0	0
1.5	50	24	25	27	29	31	32	34	36	38	39	41	1	1	1	2	2	2	2	2	2	2	2
	30	12	14	17	19	21	24	26	28	31	33	35	0	0	0	0	0	0	1	1	1	1	1
	10	03	06	09	11	14	17	20	22	25	28	30	0	0	0	0	0	0	0	1	1	1	1
	0	00	03	06	09	12	15	18	21	24	26	28	0	0	0	0	0	0	0	0	0	1	1
2.0	50	27	29	31	33	35	38	40	42	44	46	48	1	2	2	2	2	2	2	2	2	3	3
	30	14	17	20	22	25	28	31	34	37	39	42	1	1	1	1	1	1	1	1	1	2	2
	10	04	07	11	14	17	21	24	27	31	34	37	0	0	0	1	1	1	1	1	1	1	2
	0	00	03	07	11	15	18	22	25	29	32	34	0	0	0	0	0	0	0	1	1	1	2
2.5	50	29	31	33	36	38	40	43	45	47	50	52	2	3	3	3	4	4	4	4	4	4	5
	30	15	18	21	25	28	31	34	38	41	44	47	1	2	2	2	2	2	2	2	2	2	3
	10	04	08	12	16	20	24	28	31	35	39	43	1	1	1	1	1	1	1	2	2	2	2
	0	00	04	08	13	17	21	25	29	33	36	40	0	1	1	1	1	1	2	2	2	2	2
3.0	50	30	33	35	38	40	43	46	48	51	53	56	3	3	3	3	4	4	4	4	4	5	5
	30	16	20	23	27	30	34	37	41	44	48	51	2	2	2	2	2	2	3	3	3	3	3
	10	05	09	13	18	22	26	30	34	39	43	47	0	1	1	1	1	1	2	2	2	2	2
	0	00	04	09	14	19	24	28	32	37	41	46	0	1	1	1	1	1	2	2	2	2	2
4.0	50	32	35	38	41	43	46	49	52	55	58	60	3	3	4	4	5	5	5	5	5	5	6
	30	18	22	25	29	33	37	41	45	49	52	56	2	2	3	3	3	3	3	3	4	5	5
	10	06	10	15	20	25	29	34	39	43	48	53	0	1	1	1	1	2	2	2	3	3	3
	0	00	05	10	16	21	26	31	36	41	46	51	1	1	2	2	2	2	2	3	3	3	3
5.0	50	33	36	39	42	45	48	51	54	57	60	63	5	5	5	5	6	6	6	6	7	7	7
	30	19	23	27	31	35	39	43	47	51	55	60	2	2	3	3	4	4	5	5	6	6	6
	10	06	11	16	21	26	31	36	41	46	51	56	1	1	1	2	3	3	3	4	5	5	5
	0	00	05	11	17	22	28	33	39	44	49	54	2	3	3	3	3	3	3	3	4	5	5

Specimen Table 4 (a)

Room Ratio	Wall R.F. per cent	Downward Utilisation Factors—Ceiling Mounted Luminaires (Ceiling R.F. 70 per cent. Floor R.F.10 per cent.) Direct Ratio .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	Additive Correction for 30 per cent. Floor R.F. Direct Ratio .1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	50	25	34	43	52	60	69	77	85	94	1.02	0	1	1	1	2	2	2	2	2	3
	30	18	27	36	46	55	64	73	83	92	1.01	0	1	1	1	1	1	1	1	1	1
0.6	10	12	22	32	42	51	61	71	81	91	1.0	0	0	0	0	0	0	0	0	0	1
	0	10	21	31	41	50	60	70	80	90	1.0	0	0	0	0	1	1	0	0	0	0
	50	28	37	46	54	63	71	79	87	94	1.02		2	2	2	2	3	3	3	4	4
	30	19	29	38	47	57	66	75	84	92	1.01		1	1	1	1	1	1	2	3	3
0.8	10	12	22	32	42	52	62	72	81	91	1.01		1	1	1	1	1	1	1	1	1
	0	11	21	31	41	50	61	71	80	90	1.01		1	1	1	2	0	0	1	1	1
	50		39	48	56	64	72	80	88	95	1.03		2	2	3	3	4	4	4	5	5
	30		30	39	49	58	67	75	84	93	1.02		1	1	1	1	2	3	3	3	3
1.0	10		23	33	43	52	62	72	82	91	1.01		0	0	0	1	1	1	1	2	2
	0		22	31	41	51	61	71	80	90	1.01		0	0	0	1	1	1	1	1	1
	50		41	50	58	66	74	81	89	96	1.03			3	3	4	4	5	5	6	7
	30		31	40	50	58	67	76	85	93	1.02			2	2	3	3	3	3	5	5
1.25	10		23	33	43	53	63	72	82	92	1.01			1	1	1	1	2	2	2	3
	0		22	32	41	51	61	71	81	91	1.01			0	1	1	1	1	1	1	2
	50			51	60	67	75	82	90	96	1.03			4	4	5	5	6	6	8	8
	30			41	50	59	68	77	86	94	1.02			2	3	3	4	4	4	5	6
1.5	10			34	43	53	63	73	82	92	1.02			1	2	2	2	2	3	3	4
	0			32	41	51	62	72	81	91	1.02			0	1	1	1	1	2	2	3
	50			52	61	69	76	84	91	97	1.04			5	5	5	7	7	8	9	10
	30			42	51	60	69	78	87	95	1.03			3	4	4	5	5	5	6	7
2.0	10			34	44	54	64	73	83	93	1.02			2	2	2	3	4	4	4	6
	0			32	42	52	62	72	81	92	1.02			0	0	0	1	2	3	3	4
	50				62	70	77	85	91	98	1.05				6	6	7	7	9	10	10
	30				53	62	70	79	87	96	1.04				4	4	5	6	7	7	8
2.5	10				45	55	64	74	84	93	1.03				2	3	4	4	5	6	7
	0				42	52	62	72	82	92	1.02				0	1	2	3	4	5	7
	50				63	71	78	85	92	99	1.05				6	7	8	9	10	10	12
	30				53	62	71	79	88	96	1.04				3	4	4	6	6	7	8
3.0	10				45	55	65	75	84	94	1.04				3	3	4	5	6	7	7
	0				42	52	63	73	82	93	1.03				1	2	2	3	5	5	7
	50					71	79	86	93	99	1.05					9	9	10	11	12	14
	30					63	72	80	89	97	1.05					7	7	8	9	10	11
4.0	10					55	65	75	85	95	1.04					5	6	7	7	8	10
	0					53	63	73	83	94	1.04					2	3	4	5	5	7
	50					72	79	87	93	1.0	1.06					9	10	10	12	12	14
	30					63	72	81	89	97	1.05					8	8	9	10	12	13
5.0	10					56	66	76	85	95	1.05					5	6	7	9	10	11
	0					53	63	73	83	94	1.05					3	4	7	9	9	9

Specimen Table 5

Upward Utilisation Factors, Ceiling Mounted Luminaires, 10 per cent. Floor Reflectance.

Ceiling (per cent.)	70				50				30		
Walls (p.c.)	50	30	10	0	50	30	10	0	30	10	0
Room Ratio											
0.6	.23	.17	.12	.10	.16	.12	.08	.06	.07	.05	.04
0.8	.31	.24	.20	.17	.22	.17	.13	.12	.10	.08	.07
1.0	.37	.30	.26	.22	.26	.22	.18	.16	.12	.10	.09
1.25	.43	.37	.31	.29	.30	.26	.22	.2	.14	.12	.11
1.5	.47	.41	.36	.33	.33	.29	.26	.24	.15	.13	.13
2.0	.53	.48	.44	.41	.37	.33	.31	.29	.17	.15	.14
2.5	.57	.53	.49	.47	.40	.37	.34	.33	.19	.17	.16
3.0	.60	.56	.52	.5	.41	.39	.36	.35	.20	.18	.17
4.0	.63	.61	.57	.56	.44	.42	.39	.38	.21	.19	.18
5.0	.66	.64	.60	.59	.45	.43	.42	.41	.23	.20	.19

Upward Utilisation Factors. Ceiling Mounted Luminaires, 30 per cent. Floor Reflectance

Ceiling (per cent.)	70				50				30		
Walls (p.c.)	50	30	10	0	50	30	10	0	30	10	0
Room Ratio											
0.6	.24	.17	.13	.09	.17	.13	.09	.07	.09	.06	.05
0.8	.32	.25	.20	.17	.23	.18	.14	.12	.11	.09	.08
1.0	.39	.31	.26	.23	.27	.23	.19	.17	.14	.12	.11
1.25	.46	.38	.32	.29	.32	.27	.24	.22	.15	.13	.12
1.5	.51	.43	.38	.34	.35	.30	.27	.25	.17	.15	.14
2.0	.58	.51	.46	.43	.39	.35	.32	.3	.19	.17	.16
2.5	.63	.57	.52	.49	.42	.39	.36	.34	.21	.19	.18
3.0	.67	.61	.56	.54	.45	.41	.39	.37	.23	.21	.20
4.0	.71	.67	.62	.6	.48	.45	.43	.41	.24	.22	.21
5.0	.74	.70	.66	.65	.49	.47	.45	.44	.25	.23	.22

Appendix 3

Standard Luminaire Data for Some Types of Luminaire

The following data are given to enable readers t familiarise themselves with the form of the data and with their use in connection with the Tables in Appendix 2.

Luminaire — *Light Output Ratios* — *Direct and Ceiling Ratios*

Industrial dispersive reflector (filament lamp)

UP 0.0
DOWN 0.82

$s/h = 1$

Room Index	0.6	0.8	1.0	1.25	1.5	2	2.5	3	4	5
Direct Ratio	.30	.40	.49	.54	.60	.68	.73	.77	.82	.85

$s/h = 1.5$

Room Index	0.6	0.8	1.0	1.25	1.5	2	2.5	3	4	5
Direct Ratio	.32	.49	.53	.58	.62	.69	.74	.78	.83	.85

General diffusing (filament lamp)

UP 0.39
DOWN 0.45

$s/h = 1$

Room Index	0.6	0.8	1.0	1.25	1.5	2	2.5	3	4	5
Direct Ratio	.16	.23	.28	.33	.38	.46	.52	.56	.63	.68
Ceiling Ratio	.25	.32	.39	.45	.50	.58	.65	.71	.77	.81

Semi-indirect (filament lamp)

UP 0.51
DOWN 0.27

$s/h = 1.5$ and $s/h = 1$

Room Index	0.8	1.25	2.5	5.0
Direct Ratio ($s/h = 1.5$)	.48	.55	.68	.80
Direct Ratio ($s/h = 1$)	.39	.5	.68	.8
Ceiling Ratio	.56	.68	.82	.93

Fluorescent trough reflector

UP 0.0
DOWN 0.66

$s/h = 1$

Room Index	0.6	0.8	1.0	1.25	1.5	2	2.5	3	4	5
Direct Ratio	.32	.42	.49	.57	.63	.71	.76	.79	.84	.87

Fluorescent recessed louvred

UP 0.0
DOWN 0.41

$s/h = 0.8$

Room Index	0.6	0.8	1.0	1.25	1.5	2	2.5	3	4	5
Direct Ratio	.39	.48	.56	.62	.67	.74	.78	.82	.86	.88

Fluorescent semi-direct

UP 0.16
DOWN 0.40

$s/h = 0.8$

Room Index	0.6	0.8	1.0	1.25	1.5	2	2.5	3	4	5
Direct Ratio	.34	.42	.48	.54	.59	.66	.7	.74	.79	.82
Ceiling Ratio	.32	.38	.44	.50	.55	.62	.69	.74	.8	.83

UDC 628.93

Design of the Visual Field as a Routine Method

By J. M. WALDRAM, B.Sc. *(Fellow)*

Summary

The Method of Designed Appearance, which commences with the consideration of the appearance of the lighted interior and the specification of the luminances of the principal surfaces, has been applied to a simple rectangular interior. It is shown to lead to a very simple design procedure which can be reduced to a work sheet, one Table and one set of curves. Jones-Neidhart[6] ratios can be found immediately, whereby suitable equipment can be selected if these coefficients are available generally. The glare index can also be found immediately, whereby the installation can be checked for glare. The method in its simplest form is suitable for the straightforward cases and demands no specialised knowledge, but is capable of elaboration to any extent which the situation may justify.

It is recommended that a code be prepared giving guidance on the specification and luminance factors in typical cases.

Introduction

A method of lighting design known as "Designed Appearance" has been described [1,2,3] in which the design commences by a specification of the luminance of the principal surfaces of an interior, and is completed by the selection of the lighting equipment and its position. The method is capable of elaboration to the degree justified by the project. It may commence by a specification of apparent brightness and take into account the adaptation level, in order to arrive at the specification of luminance at which the design proper commences; it may also introduce effects of modelling and emphasis. It greatly simplifies calculation of glare. The method is capable of handling projects of great complexity; but such projects are rare, and there is greater interest in the possibility of applying it to simple routine projects, with reasonable speed, where refined design is not called for. The present note describes such an application, showing that the method can be reduced to very simple terms capable of being used by non-expert designers. Moreover, it links conveniently with the initial stages of the Jones-Neidhart method[6] so that data prepared for that method will be directly useful to the Designed Appearance Method.

(1) Example of Application to a Simple Interior

The application to a straightforward interior will be described by way of example. Consider a small light-assembly shop, shown in the drawings of Fig. 1, measuring 20 ft. x 30 ft. x 12 ft. high, in three bays, with three large windows not provided with blinds. There are three benches in the centre of the room, one long bench under the windows and some cupboards.

Reflection factors are shown in Table 1.

Table 1

Reflection factors

(mean during life; per cent.)

Walls	40
Ceiling	65
Floor	15
Benches	30
Cupboards	10
Windows (night)	15

(1.1) First step: specify the luminance required on each principal surface

This can be conveniently done by specifying first the required apparent brightness [3,4], estimating the adaptation level and finding the corresponding luminances. The introduction of apparent brightness may be omitted and the specification written down directly in terms of luminance (guidance in specifying suitable combinations of luminance may be given later by a code (see Section 2.4.)), but the use of apparent brightness is, however, recommended, for it is realistic and helps in drawing a sensible specification. Similarly the perspective shown is not essential but is valuable, even if not drawn formally to scale. Since apparent brightness is an unfamiliar conception, it will be explained in some detail.

(1.1.1) *Discussion*

The scale of "Apparent Brightness" is subjective and purely numerical, and it is a correlate of "luminosity" and appears to accord with visual experience of "brightness" much better than do values of luminance, which do not take into account the effects of adaptation. The scale

The author is with the Research Laboratories of the General Electric Co. Ltd. The manuscript of this paper was first received on March 19, 1958, and in revised form on May 6, 1958.

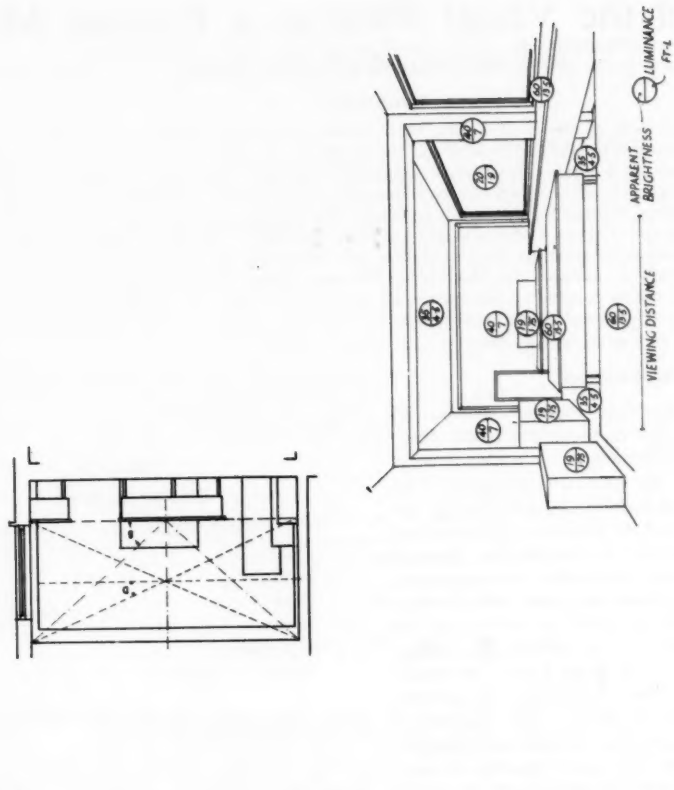


Fig. 1. Hypothetical example of the design of the visual field. A small light assembly shop measuring 20 ft x 30 ft x 12 ft high.

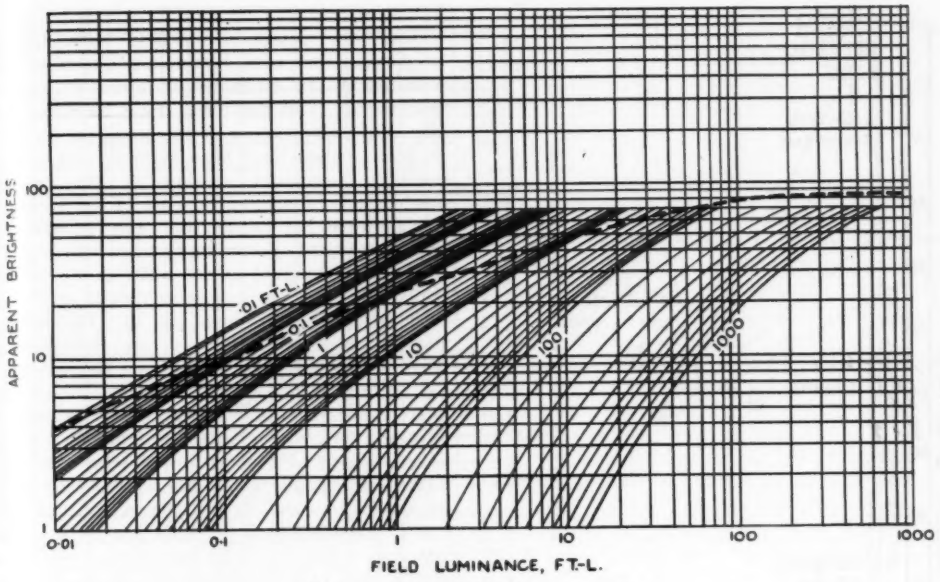


Fig. 2. Apparent brightness curves.

was derived by Hopkinson[4], and for the present purposes is defined by the curves of Fig. 2 which relate apparent brightness and luminance for various adaptation levels, each of the family of curves being drawn for a given value of adaptation level in luminance, for which adaptation level the corresponding curve gives the transformation from field luminance (abscissae) to apparent brightness (ordinates). For the present purposes, these curves define apparent brightness.

The values of apparent brightness are somewhat analogous to values of temperature on the Fahrenheit scale; that scale is arbitrary, but the numbers correspond to experience of warmth, and from experience they can be used to specify, say, a suitable temperature for an interior which will be appropriately comfortable. Similarly, values of apparent brightness correspond roughly to sensations of "brightness" or luminosity and by experience with other interiors can be used for specification of suitablelu minances which will give the desired visual effect. As a guide to specification, Fig. 3 has been prepared showing typical values, taken from a number of examples previously studied. The specification for a given interior is written down from experience. The numbers are absolute, as are those of the Fahrenheit scale, not relative.

Table 2, Col. 1, shows the specification for the present example, in terms of apparent brightness: the values are also marked on the perspective. That of the bench tops has been set high (60) and that of the walls, which often form the immediately adjacent field, is still high (40), but lower than the benches. The ceiling is less at 35. The specification of luminance is found from that of apparent brightness using the curves of Fig. 2, as shown below.

Table 2
Apparent brightness and luminance specification

1 Location	2 Apparent Brightness	3 Luminance ft-L.	4 Reflection Factor	5 Total Illumination lm/ft^2
Benches	60	13.5	0.30	45
Floor	35	4.5	0.15	30
Walls	40	7	0.40	17.5
Ceiling	35	4.5	0.65	6.8
Adaptation level	40			

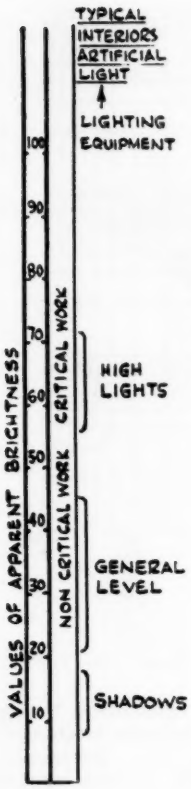
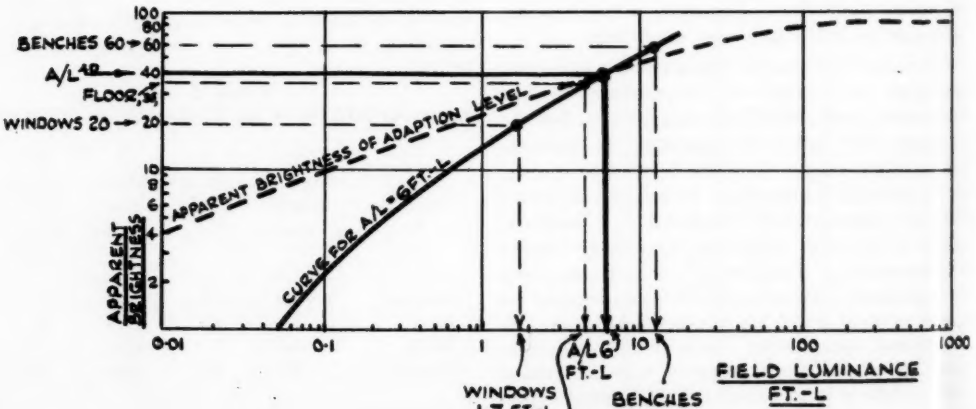


Fig. 3. Scale of Apparent Brightness and some typical values.

Fig. 4 (below). Use of curves of Apparent Brightness.

(1.1.2) *Calculation*

Since the design commences with apparent brightness, not with luminance, the adaptation level has to be estimated in terms of apparent brightness. This has been done by scrutinising the perspective sketch of the scene on which the proposed values have been marked, and taking mentally estimated average of the apparent brightnesses in the central part of the scene. In the example the perspective (Fig. 1) shows the apparent brightness of the benches which will be the centre of regard at 60, walls at 40, floor 35, cupboards, windows and some details at 20, the estimated adaptation level was 40. The curves of Fig. 2 are now used as follows: find the adaptation level (40) on the scale of apparent brightness (see Fig. 4) and follow this level across to meet the heavy dotted curve. This curve relates the apparent brightness and the luminance of the adaptation level; it is drawn through points which correspond to an observer looking at the luminance to which he is adapted, e.g. looking at 1 ft-L when adapted to 1 ft-L, to 10 ft-L when adapted to 10, etc. The intersection corresponds with a value of 6 ft-L on the scale of abscissae, and the curve of adaptation level 6 ft-L is, therefore, used to transform the specified apparent brightnesses into luminances. Some typical points are indicated in Fig. 4 corresponding to values found in Table 2. The luminances thus found appear in Col. 3 of Table 2.



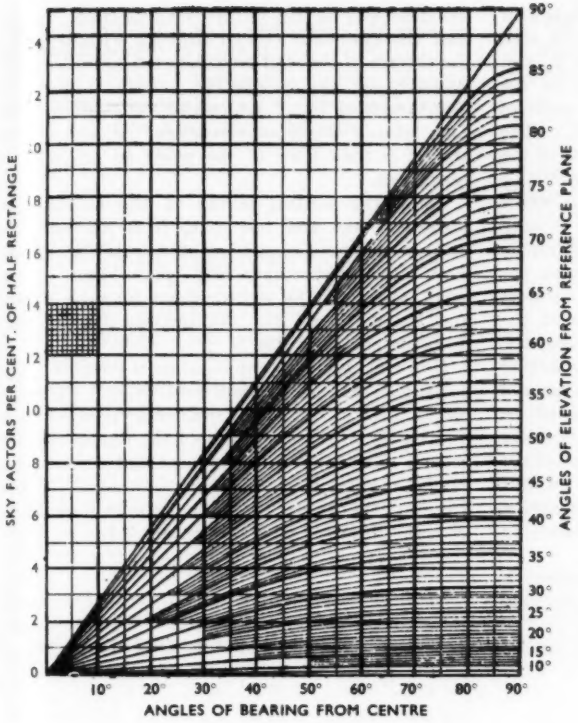

SKY FACTORS PER CENT. OF HALF RECTANGLE
ANGLES OF ELEVATION FROM REFERENCE PLANE
ANGLES OF BEARING FROM CENTRE
10° 20° 30° 40° 50° 60° 70° 80° 90°
90° 85° 80° 75° 70° 65° 60° 55° 50° 45° 40° 35° 30° 25° 20° 15° 10°

Fig. 5.

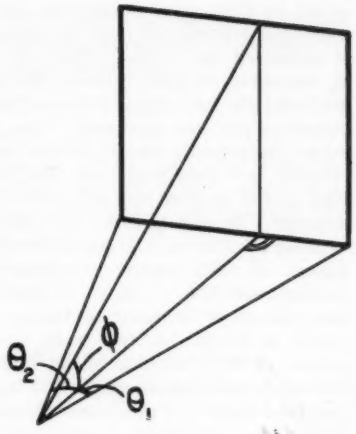


Fig. 6.

(1.2) Second step: Finding total illumination required

Values of reflection factor are inserted (Col. 4) and the total illumination required on each surface found by dividing the luminance by the reflection factor (Col. 5)*.

*The specification should be scrutinised at this stage for consistency For example, in the present case the apparent brightness of the ceiling was first made 30, leading to a required total illumination on it of 5.75 lm/ft². It was, however, noted that the luminance of the benches was 13.5 ft-L and that of the floor 4.5; the mean luminance of the working plane could be taken as 6.8. The luminance of the walls was 7 ft-L. Thus the interreflection illumination on the ceiling would be about 6.9 lm/ft² (see below), or more than the required total. The specification of the ceiling apparent brightness was, therefore, altered to 25, since the value specified was not critical. Another possibility might have been to alter its reflection factor.

The situation should also be scrutinised for the probable quality of the lighting, and the probable form of the light distribution. In the present case, had the reflection factor of the benches been 0.25 and that of the wall 0.55, the Table would have shown that the benches would require 50 lm/ft² and the walls about 13, of which they would receive 5-6 lm/ft² by interreflection. This would mean that the light distribution of the luminaires would be very concentrating; the benches would receive 50 lm/ft² by direct light and 5 by interreflection, and since the distribution is very concentrating, few luminaires would contribute to any point and the shadows might be hard, though the use of tubular fluorescent luminaires would mitigate them for some directions. See Section (2.4).

(1.3) Third step: Calculation of illumination received by interreflection

(1.3.1) *Discussion*

A point on any of the principal boundary surfaces views a complete surround consisting of five other surfaces, each (in simple cases) rectangular, and of known luminance. Each such surface acts as a window illuminating the point, giving an illumination equal to its " sky factor " multiplied by its luminance. In the present method of calculation the final luminance is already known. Since natural daylight is not involved the sky factor will be here designated the " Illumination Factor." The sky factor at a point on a horizontal plane for a simple rectangular vertical window is most conveniently found from the curves of Fig. 5([5]), which give the sky factor for that part of the window lying to one side of the normal through the point of reference, in terms of the angle θ in plan of the side of the window, and the angle in elevation ϕ of the top of the window in the plane of the normal. (See Fig. 6.) To determine the contribution of reflected light from any wall to a point on the working plane, therefore, a

point on that plane is selected and the angle of elevation ϕ from that point to the top of the wall is measured, on section. The two angles θ_1 and θ_2 measured on plan between the normal to the wall and the two edges of the wall at the point of reference are also measured. (See Fig. 6.) The two corresponding factors, for the two parts of the window, are then read from the curves of Fig. 5 and added to give the sky factor for the whole window. In the present calculation it is convenient to select as a point of reference the centre points of each surface, so that all cases are symmetrical and so that corresponding surfaces have the same illumination factors. Thus if the factor is found for two walls illuminating the centre of the working plane, the illumination factors for the other two walls will be the same, and the total factor for the four walls together will be double the sum of the factors for the two walls. The factor for the ceiling is the complement of the total wall factor, since the factors for all five surfaces total 100 per cent.; for the illumination of a surface surrounded by a complete " sky " of luminance B ft-L is equal to B lm/ft².

The illumination received from each surface is then the product of its luminance and its illumination factor.

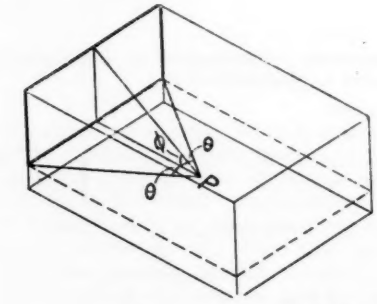
The light received *on* a wall is treated in exactly the same way as that on the working plane, except that the system is turned through a right angle, the surface of the wall being treated as horizontal; similarly for the ceiling the system is inverted. The sketch of Fig. 7 will make the process clear. The terms " angle of elevation " ϕ and " plan angle " θ then refer to the plane of the surface concerned.

Using the central points of the ceiling, the working plane and one wall, it is necessary to measure only six angles, as shown in Fig. 8, and from these the corresponding " plan " and " elevation " angles can be written down for each surface and the corresponding illumination factors read from the curves of Fig. 5.

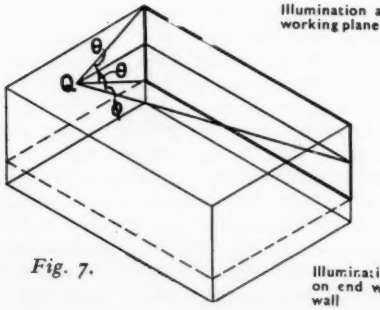
However, further simplification is possible. The six angles are interrelated, and depend upon the proportions of the room, defined by l/w and h/w (see Fig. 8); if these are known the angles and the various illumination factors are determined and can be tabulated once for all in terms of l/w and h/w for the centres of the principal surfaces. (For the meaning of h see Section 2.1.)

(1.3.2) *Table of illumination factors*

A single table can be prepared, giving for various values of l/w and h/w the values of the illumination factor for the ceiling, illuminating the centres of

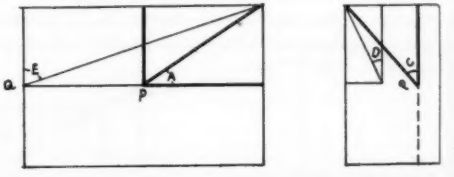


Illumination at point P on working plane from end wall



Illumination at point Q on end wall from side wall

Fig. 7.



Tan A=W/L
Tan B=2H/L
Tan C=2H/W
Tan D=H/W
Tan E=2L/W
Tan F=2L/H

AT POINT P IN CENTRE OF W.P.:
For end wall θ=A; ϕ=B
For side wall θ=90°−A; ϕ=C
Ceiling by difference

AT POINT Q IN CENTRE OF WALL:
For side wall θ=D; ϕ=E
For ceiling θ=90°−D; ϕ=F
W.P. Same as ceiling
End wall by difference

Fig. 8.

the working plane and of one wall. The form of the table is shown in Table 3.

Table 3

Ceiling illumination factors for points in centre of working plane and wall

h/w \ l/w		1	2	3	4	5
2	WP	.072	.128	.156	.202	.228
	W	.071	.118	.126	.14	.144
1	WP	.24	.368	.416	.432	.442
	W	.188	.234	.24	.242	.242
1/2	WP	.552	.672	.692	.698	.7
	W	.32	.342	.346	.348	.35
1/3	WP	.736	.816	.828	.834	.834
	W	.376	.392	.394	.396	.396
1/4	WP	.832	.888	.892	.894	.894
	W	.404	.416	.42	.42	.42
1/5	WP	.856	.908	.91	.91	.912
	W	.424	.436	.44	.44	.44

These data can also be presented graphically and are plotted in Figs. 9 and 10.

If the factor at a point is known for the ceiling, the factor at that point for the other surfaces can be found very simply, as follows :—

(1.3.3) *Operation*

From the values of l/w and h/w, find the illumination factors for the ceiling, illuminating the centres of the working plane and one wall. In the present case they are :—

Working plane	0.68
Wall	0.35

Interreflection component on working plane

From ceiling : (Luminance 4.5 ft-L)
Illumination is 0.68 x 4.5 ... 3.05 lm/ft²
From walls :(Luminance 6.16 ft-L allowing for blinds*) Illumination factor is (1 – 0.68) or 0.32.
Illumination is 0.32 x 6.16 ... 1.97

Total 5.02 lm/ft²

*See summary of calculation and Note 1.

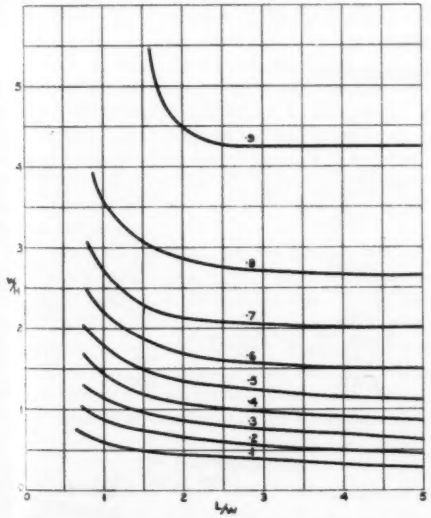


Fig. 9. Illumination Factors for ceiling at point on working plane.

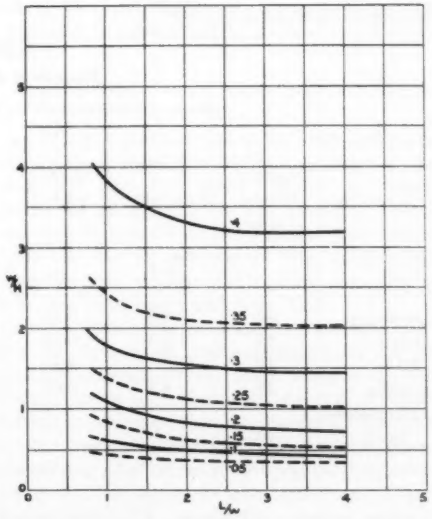


Fig. 10. Illumination Factors for ceiling or working plane at point on wall.

Interreflection component on ceiling

From working plane: Illumination factor is identical with that of ceiling on working plane, by symmetry. Mean luminance of working plane is 6.8 ft-L*.

Illumination is 0.68 x 6.8 ... 4.64 lm/ft²

From walls: Illumination on ceiling is same as on working plane, by symmetry 1.97

Total 6.61 lm/ft²

Interreflection component on walls

From ceiling:

Illumination is 0.35 x 4.5 ... 1.57 lm/ft²

From working plane: Illumination factor is same as for ceiling, by symmetry.

Illumination is 0.35 x 6.8 ... 2.38

From other walls: Illumination factor is (1—2 x 0.35) or 0.3

Illumination is 0.3 x 6.16 ... 1.86

Total 5.81 lm/ft²

(1.4) Fourth step: Calculation of direct illumination

The values just found can be inserted in the continuation of Table 2 (repeated for clarity) in Col. 6, and the direct illumination required on each surface (Col. 7) found by subtracting from the total required illumination (Col. 5) the illumination received by interreflection from the other surfaces (Col. 6).

(1.5) Fifth step: Direct luminous flux required

The direct luminous flux required is found by multiplying the area of each principal surface (Col. 8) by the required direct illumination (Col. 7). (For this purpose the overall area of the working plane is taken, as though it were covered with benches at 40 lm/ft².) If the light output ratio of the luminaire is 0.6 (mean during life) the lamp flux required will be 34,500/0.6 or 57,500 lumens from the lamps, mean during life.

(1.6) Sixth step: Number, rating and location of luminaires

The required flux can be obtained by several different combinations of lamps; the most convenient for spacing and arrangement in this case is to use 18 single 80-watt fluorescent lamps, natural colour, arranged as shown in Fig. 1—six per bay. The spacing will be 5 ft x 6 ft 8 in. and height above working plane (for ceiling mounted units) 9 ft, giving a spacing-height ratio of 0.65. The room index is $wl/(w + l)\ h_{wp} = 600/(50 \times 9) = 1.33$.

(1.7) Seventh step: Selection of luminaire distribution

From the figures in the fifth step (Col. 9) the flux to working plane, walls and ceiling can be

*See summary of calculation and Note 1.

Table 2 (*contd.*)

Required direct illumination

1 Location	2 Appart. Bright-ness	3 Luminance	4 Refln. Factor	5 Total Illum.	6 Inter-refln. Illum.	7 Direct Illum.	8 Area	9 Direct Flux
		ft-L		lm/ft²	lm/ft²	lm/ft²	ft²	lm
Benches	60	13.5	0.30	45	5.02	40	600	24,000
Floor	35	4.5	0.15	30*	3 approx.	27 approx.		
Walls	45	7	0.40	17.5	5.81	11.7	900	10,500
Ceiling	35	4.5	0.65	6.8	6.61	0.2	600	
Adaptation level	40							
							Total direct flux	34,500

*The illumination on the floor partly screened by benches has not been worked out in detail and is not critical; if the benches receive 45 lm/ft², the illumination on the floor may reasonably be about 30 or less.

found; the former expressed as the fraction of the flux below horizontal, is the direct ratio of the Jones-Neidhart method(6). The proportion of flux above and below the horizontal can be found. In this case the flux above horizontal is evidently 0; that below will be 1.0. The direct ratio is 24,000/34,500 or 0.7.

The method at this point links with the Jones-Neidhart method. The I.E.S. Technical Committee recommends that a variation of the Jones-Neidhart method be used, and that tables should be prepared for every luminaire showing the proportion of flux above and below the horizontal, and the direct and ceiling ratios as a function of spacing-height ratio and room index. If such information is available, therefore, it remains to select an 80-watt luminaire having these ratios; in the present case a luminaire was found having a concentrating distribution which gives fairly closely the required direct illuminations, using mirrors so that the luminance of the luminaire is low as seen from working positions.

(1.8) Eighth step: Check of glare index

Having selected the luminaire, and knowing the luminance of the luminaire at appropriate angles, it remains to calculate the glare index. It will be worst for a position near the wall from which the maximum number of fittings can be seen; the index is given by $(B_s/B_g)\ \Sigma E$, where B_s is the source luminance and B_g the background luminance, and ΣE the illumination on the eye from all the sources. B_s is characteristic for the luminaire; B_g will be the ceiling luminance, in this case 4.5 ft-L, and E the direct illumination from the luminaires on the eye, which will be closely the same as that on the walls, or 11.7 lm/ft². This glare index can, therefore, be calculated and checked that it does not approach the limit for discomfort. If it does, it will be necessary to redeploy the light sources and choose a different type of luminaire.

The whole of the calculations are set out on the single work sheet (see page 122). Nothing more elaborate than simple arithmetic is required; there is a little more of it than is called for in the flux method, but the present method of design undertakes far more than does the flux method, for it is concerned with the whole visual field, not merely with illumination on the working plane.

(2) Refinements

(2.1) Treatment of floor and working plane, and of ceiling

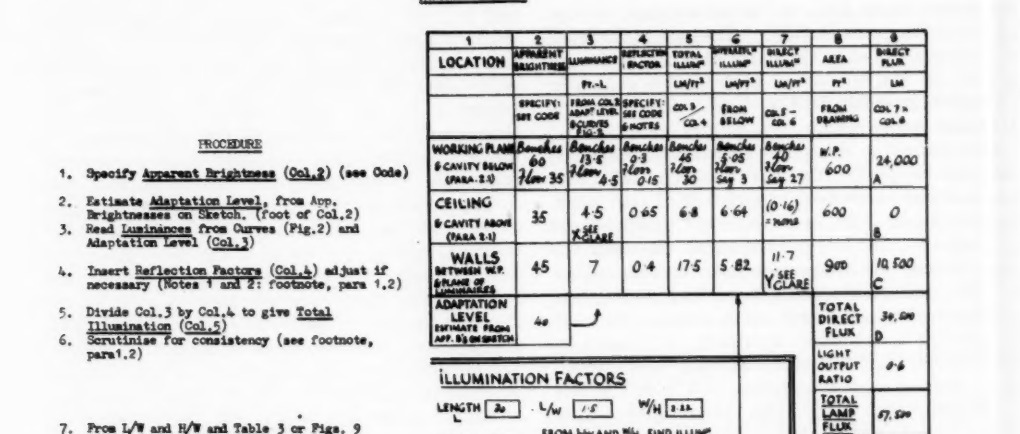
In general, it is recommended that, as has been suggested by Zijl(7), the interior is considered as a rectangular space, bounded by part of the walls and by two cavities, a lower one bounded by the (real) working plane and consisting of the cavity below it formed by the floor and that part of the walls below the working plane, and the upper one bounded by the plane of the luminaires (if suspended) and consisting of the cavity above it formed by the ceiling and that part of the walls lying above the plane of the luminaires. The height h used in calculation is the height from the lower to the upper bounding plane. This conception is simplified if the part of the walls above the level of the fittings is decorated to match the ceiling. The luminance ascribed to each of the cavities should be estimated from that of their components. The treatment of the floor, however, will depend upon local conditions, in particular on whether there is a physical working plane consisting of tables or benches or machines, or whether the interior is empty, as in a waiting-room. In the latter case the bounding plane can be taken as the floor, and the conception of a working plane omitted. However, if there is an empty room having a dado, the reflection factor of which approximates to that of the floor rather than to that of the walls, then the lower bounding plane can be taken as the plane of the dado. The method must be varied to calculate what is required.

It is possible in this way to treat ceilings which are not plane, such as domed or vaulted ceilings, north-light or lantern ceilings, and the like. In general, the reflection factor of the ceiling surface is reduced, as described in Note 2 to the work sheet.

(2.2) Non-uniform walls

(a) If the luminance of some walls, or parts of walls, differs from the remainder, then a mean luminance can be taken, which is generally sufficiently accurate. In the present case, this procedure is applied to the window wall when the blinds are not drawn and to the working plane consisting of benches with floor seen between them (see work sheet and Note 1).

It may sometimes be necessary to work out the effect of some such non-uniformity on the inter-reflected component on some surface of special interest, or to find the interreflection component at some other point than the centre of the surface, e.g. the window bench. This may be done by abandoning the table or graphs of illumination factors and working out the individual illumination factors for particular points using the appropriate angles and the curves of Fig. 5. This is a simple calculation and takes only a few



PROCEDURE

1. Specify Apparent Brightness (Col.2) (see Code)
2. Estimate Adaptation Level, from App. Brightnesses on Sketch. (foot of Col.2)
3. Read Luminances from Curves (Fig.2) and Adaptation Level (Col.3)
4. Insert Reflection Factors (Col.4) adjust if necessary (Notes 1 and 2: footnote, para 1.2)
5. Divide Col.3 by Col.4 to give Total Illumination (Col.5)
6. Scrutinise for consistency (see footnote, para1.2)
7. From L/W and H/W and Table 3 or Figs. 9 and 10 find ceiling Illumination Factors for Working Plane and Walls.
8. From Mean Luminance of Ceiling, Working Plane and Walls (found if necessary as shown in bottom panel) and from Illumination Factors, find Interreflection Components on W.P., Walls and Ceiling, Insert in Col.6.
9. Subtract Col.6 from Col.5 to give Direct Illuminations (Col.7)
10. Multiply Direct Illuminations (Col.7) by areas of surfaces (Col.8) to give Direct Flux from luminaires (Col.9) and sum for Total Direct Flux.
11. Divide Total Direct Flux by Light Output Ratio of luminaires to give Total Lamp Flux.
12. Find Direct Ratio and Flux Distribution as indicated.
13. Decide number and type of lamps and layout to give best approximation to total lamp flux.
14. Calculate Room Index and Spacing-Height Ratio.
15. Select luminaire giving nearest Direct Ratio and Flux Distribution for Room Index and Spacing-Height Ratio.
16. Calculate Glare Limit as shown and check that it is not excessive.

minutes. It is, of course, worth doing only if as the result of the calculation it is possible to take steps in the installation to allow for the difference found.

(b) The method gives the total flux to the walls and other surfaces; it does not guarantee that it will be uniformly distributed. If the distribution of luminance is important, the distribution of incident direct illumination can be worked out; in many cases it may suffice to take only the nearest row of fittings, which will be mainly responsible for variations in the distribution. This can conveniently be read from a Federov diagram([8]) or by a diagram as shown in Reference([3]), if available, for a single luminaire, and the distribution obtained by summation.

(2.3) Special arrangements

The method as outlined has been reduced to simple terms, using a conventional array of standard equipment, so that it can be used by non-specialists. The more experienced engineer can elaborate it as he wishes at any point, for all

the steps and approximations are clear. He may employ such devices as different luminaires near the walls to light them independently of the luminaires used for general illumination; supplementary lighting by spotlights or reflector lamps, etc.; or to the point of specially designed systems of concealed lighting in the very elaborate installations.

(2.4) Importance of reflection factors: Code for luminance specification

It has become evident that in any system whatever of Design of the Visual Field, the lighting engineer must have some control of the reflection factors of principal surfaces, and also that the specification of luminances and reflection factors will probably need adjustment in order to arrive at the best combination. The more nearly the distribution of luminance can be achieved by the reflection factors, the less will critical distributions, cut-offs and settings of luminaires be required, and the simpler will it be to use standard equipment. However, if the walls are of higher reflection factor, they will require less light for a given luminance; it is, therefore, possible to use equipment which sends less light to the walls, and consequently there will be less glare.

It follows that there is scope, therefore, for the determination of appropriate distributions of luminance and of related reflection factors which can be codified for guidance to help in the sensible specification of apparent brightness or luminance in the first step, and such a code is in any case most desirable whatever system of design is used.

Notes on use of work sheet

(1) Mean reflection factor or mean luminance

The allowance for variable reflection factor of walls, etc., can be made in two ways, according to what is required. If it is desired to produce a mean luminance, allowing for the areas of lower luminance, equal to the specified figure, then the *mean reflection factor* should be calculated and inserted in Col. 4. If however it is desired that the luminance of the surface in the important regions should be that specified, and it is accepted that in some regions it may be lower because the reflection factor is locally reduced (e.g. at the windows in this example if the blinds are not provided) then the nominal reflection factor should be used in Col. 4, and the *mean luminance* calculated as shown and inserted in the calculation for inter-reflection. The latter procedure is used here.

(2) Equivalent reflection factor of cavity

For suspended luminaires and some other situations, the ceiling or upper bounding plane is assumed to lie in the plane of the luminaires; the real upper surfaces consist of the real ceiling plus the part of the walls above the bounding plane. Or the real ceiling may be a dome, vault or north-light or similar construction. In this case the reflection factor assumed for the bounding plane is the reflection factor of the real ceiling reduced in the proportion of the area of the bounding plane to the area of the real ceiling. Further allowance can be made for the obstruction of the luminaires.

(3) Check of design

The available luminaire and lamp combinations will probably not permit very close adherence to the requirements for direct illumination, either as to uniformity or absolute value. The designer may wish to check this, for which purpose the distribution of illumination from the nearest row of luminaires will be a good guide to uniformity.

The general design can be checked by the utilisation factor method, using Jones and Neidhart factors.

References

(1) Waldram, J. M., Studies in Interior Lighting. Trans. Illum. Eng. Soc. (Lond.), **19**, 95 (1954).

(2) Waldram, J. M., A New Approach to Interior Lighting. *Arch. Jour.*, **120**, 113 (1954). *G.E.C. Jour.*, **21**, 221 (1954).

(3) Waldram, J. M., The Design of the Visual Field. A New Approach to Interior Lighting. C.I.E. Comptes Rendus, 1955, **I.**

(4) Hopkinson, R. G., Stevens, W. R., and Waldram, J. M., Brightness and Contrast in Illuminating Engineering. Trans. Illum. Eng. Soc. (Lond.), **6**, 37 (1941).

(5) Waldram, P. J., A Note on Post-war Fenestration. *R.I.B.A. Jour.* (March, 1944).

(6) Jones, J. R., and Neidhart, J. J., Coefficients of Utilisation for Luminaires with Concentrating Distributions. Ill. Eng. (U.S.A.), **46**, 601 (1951). The Zonal Method of Computing Coefficients of Utilisation and Illumination on Room Surfaces, ibid, **48**, 141 (1953).

(7) Zijl, H., Computed Coefficients of Utilisation. C.I.E. Comptes Rendus, 1955, **I.**

(8) Federov, B. F., "Lighting Technique," p. 116 (Hutchinson, London, 1944).

Supplementary Note

By W. ROBINSON *(Chairman, Lighting Design Data Panel of the Technical Committee)*

It is fortunate that Mr. Waldram should be in a position to contribute his paper on " The Design of the Visual Field as a Routine Method " at the same time as the L.D.D. Panel's contribution, for the link between the Zonal Method of illumination design and luminance design becomes very apparent on reading both contributions. It is, perhaps, not inappropriate to consider very briefly in what other ways the Zonal Method and the interreflection data accompanying it, can facilitate luminance design.

Waldram has evolved Illumination Factors by which the illumination at a point on a surface received from all other contributing surfaces can be obtained simply. The Building Research Station has similarly tackled the same problem with particular regard to day-lighting problems and has produced the well-known B.R.S. Daylight Factor Protractors and data which are now familiar to architects. R. O. Phillips, in Australia, has calculated luminance transfer functions, called by him P_k functions, which, by definition, give the proportion of the total flux emitted by the ceiling which reaches the walls. These are dependent only on the room proportions and are tabulated for the normal range of room indices. They are operated in a similar manner to Waldram's Illumination Factors, but whereas the use of Illumination Factors (as tabulated in Waldram's paper) gives the illumination received at a point, the use of Phillips's P_k factors gives the average illumination over the whole reference surface. Where the resulting wall luminance is uniform the two approaches give the same result.

The combination of standard luminaire data, (i.e. Light Output Ratios, Direct and Ceiling Ratios), the interreflection data contained in the Tables of Utilization Factors, and illumination factors or luminance transfer functions, gives us all that is necessary either to produce a preselected luminance pattern (Waldram's " Designed Appearance ") or to calculate the overall luminance pattern resulting from an illumination design by the Zonal Method. The latter facility is due to the fact that the Zonal Method not only gives the total flux to the floor, but also separates this into the direct and interreflected components. The direct component of ceiling and wall illumination is also known from the standard luminaire data and from this combined information the final wall and ceiling average luminances can be determined without difficulty. Waldram has shown also how a figure of glare discomfort can be obtained for Designed Appearance installations and since average interior luminances can be obtained for an installation designed by the Zonal Method a " glare index " can be similarly found for it.

It has to be realised, of course, that there may be considerable variation between the average luminance of room surfaces and the luminance of any part of them. It must also be appreciated that the application of zonal data to practical luminance design is at present restricted to symmetrical uniform systems and even then with certain qualifications. There is still much work to be done before full luminance design, applicable to non-symmetrical as well as symmetrical luminaire arrangements, and to non-uniform flux distributions, can come into regular use, but work on this is proceeding. The " next step " envisaged by the L.D.D. Panel, namely the classification of luminaires on the basis of their zonal flux distribution, and the substitution of basic interreflection data for empirical data, involves primarily the refinement of existing data but at the same time it represents a fundamental change in the direction of lighting technique which has to occur sooner or later.

Is there any time better than the present ?

Additions to the List of Members

The following applicants have been duly elected by the Council to membership of the Society :—

Sustaining Members

Dernier & Hamlyn Ltd., 23 Newman Street, London, W.1.
Representative : P. Hall.

Harris & Sheldon (Electrical) Ltd., Ryder Street, Birmingham, 4.
Representative : H. R. T. Ball.

North Western Gas Board (Liverpool Group), Radiant House, Bold Street, Liverpool, 1.
Representative : A. E. Alexander.

Corporate Members

Acraman, E. R.	10 Broomloan Lane, Sutton Common, Surrey.
Balakrishnan, A.	Installation Section, Dept. of Electricity, P.O. Box 12, Kuwait, Arabia.
Balder, Ir. J. J.	Lichttechnisch Lab., N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.
Bates, E.	North Eastern Electricity Board, Carliol House, Newcastle-upon-Tyne, 1.
Bickerdike, J.	88 George Street, Portman Square, London, W.1.
Birtwell, D.	3 Brocklehurst Street, Moston, Manchester, 9.
Boud, J. K.	Flat 1, 10 Spring Street, London, W.2.
Bromet, S. J. W.	Kineton, Warwicks.
Burgess, H.	14 Barnsdale Avenue, Thingwall, Wirral.
Burgin, R.	22 Balmoral Road, South Harrow, Middlesex.
Capell, R. S.	c/o, The British G.E.C. Ltd., P.O. Box 15, Queens Buildings, Chater Road, Hong Kong.
Cassal, C. V.	25 Beeches Walk, Carshalton, Surrey.
Charters, A. D.	50 Grosvenor Road, Wallington, Surrey.
Cialis, G. J.	6 Holland Park Road, London, W.14.
Clague, W. R.	185 Eaton Road North, Liverpool, 12.
Clemmit, T. J.	74 Granville Drive, Forest Hall, Newcastle-upon-Tyne, 12.
Crane, G.	6 Rosewood Avenue, Skew Bridge, Blackburn.
Creswell, D. R.	48 Dorchester Way, Kenton, Harrow, Middlesex.
Crompton, A.	130 Ashton Road, Oldham.
Curtis-Brindle, C.	53 Victoria Street, London, S.W.1.
Davis, J.	1 Marlborough Hill Place, Cotham, Bristol, 2.
de Boer, J. B.	c/o, Lighting Lab., N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.
Denstone, D. G.	73 Southfield Avenue, Castle Bromwich, Warwicks.
Dunsford, R. V.	6 Macaulay Court, Macaulay Road, London, S.W.4.
Eade, S. R.	Limbreys, Broughton Astley, Leics.
Endersby, G. P.	112 Northwood Avenue, Elm Park, Hornchurch, Essex.
Ferreira, C. A.	Gral. Las Heras 1896, Casilla de Correo 294, Montevideo, Uruguay.
Foster, H.	4 Downs Cote Park, Westbury-on-Trym, Bristol.
Fuller, J. W.	c/o, The G.E.C. Company of India (Private) Ltd., Magnet House, Mount Road, P.O. Box 351, Madras 2, S. India.
Garside, S. J.	6 Southsea Street, Hr. Openshaw, Manchester, 11.
Goddard, C. E.	10 Teignmouth Road, Cricklewood, London, N.W.2.
Grant, F.	61 Woodland Way, Winchmore Hill, London, N.21.
Griffiths, A. E.	c/o, City Engineer's Dept., Council House, Coventry.
Halford, W. H.	519 H.Q. Road, Marqil, Basrah, Iraq.
Hards, W. C. E.	18 Heston Avenue, Patcham, Brighton, 6, Sussex.
Hawcourt, M.	62 Trafalgar Street, Ashton-under-Lyne, Lancashire.
Heazell, F. A.	16 Ashton Drive, West Kirby, Wirral, Cheshire.
Hendry, J. W.	105 Lulworth Avenue, Simonside, Jarrow, Co. Durham.
Hickinbottom, T. W.	13 Almond Grove, Fairfield, Stockton-on-Tees, Co. Durham.
Hinsley, D. H.	15 Pelham Street, Bardsley, Oldham, Lancashire.
Hogg, A. L.	33 Todd Lane North, Lostock Hall, Nr. Preston, Lancs.
Horrobin, A. K.	287 Sandon Road, Meir Heath, Stoke-on-Trent, Staffs.
Huggett, W.	20 Greenway, Great Crosby, Liverpool, 23.
Hunter, E. R.	25 Gondover Avenue, Orrell Park, Liverpool, 9.
Huxtable, W. A.	E.L.H.V. Section, City Eng. Dept., Council House, Coventry.
Jennings, H.	28 Cavan Road, Liverpool, 11.
Lambert, B. H.	100 Hatton Hill Road, Litherland, Liverpool, 21.
Lawrence, F. N.	90 Rochester Avenue, Feltham, Middlesex.
Le Grand, Y.	57 Rue Cuvier, Paris 5, France.
Logan, H. L.	5 Hewitt Avenue, Bronxville, N.Y., U.S.A.
Lyle, K.	c/o, Siemens Edison Swan Ltd., Caxton House, Westminster, S.W.1.
Macharg, J. A.	c/o, The Nova Sign Company, Central Buildings, Wallsend, Northumberland.
Maunder, G. G.	71 Penfillia Road, Brynhyfryd, Swansea.
McShane, T.	P.O. Box 1354, Nassau, Bahamas.

Meek, R. E.	Tally Ho! Edgbaston Road, Birmingham, 5.
Mogens, V.	Noerregade 36, Copenhagen K, Denmark.
Monk, H. W.	29 York Avenue, Wolverhampton, Staffs.
Moore, P. E.	45 Northumberland Avenue, Hornchurch, Essex.
Moule, J. W.	South of Scotland Electricity Board, P.O. Box 173, 351 Sauchiehall Street, Glasgow, C.2.
Mounsten-Harrison, H.	1 Wickham Avenue, Cheam, Surrey.
Moxley, R. J.	Prior's Field, Abbots Leigh, Nr. Bristol.
Muggeridge, G. R.	14 Corrigan Avenue, Coulsdon, Surrey.
Mulcahy, S.	70 Merrion Square, Dublin.
Newsome, A.	31 Metcalfe Street, Wakefield Road, Bradford, 4.
Orford, J.	9 Kentish Town Road, Camden Town, N.W.1.
Oswell, K. L.	68 Chaworth Road, West Bridgford, Nottingham.
Perera, H. A.	55 Pearson Park, Beverley Road, Hull.
Picard, P. A.	1 Norris Green Crescent, Liverpool, 11.
Pieksma, D. H.	P.O. Box 2074, Cape Town, South Africa.
Powell, W. J. E.	2 Plasturton Avenue, Cardiff.
Ramaswamy, S.	Lighting Fittings Dept., M/S General Electric Co. of India Ltd., Magnet House, Dougall Road, Ballard Estate, Bombay, India.
Ravenscroft, W. J.	12 Middleton Road, Fairfield, Liverpool, 7.
Reeves, G.	10 Ardleigh Green Road, Hornchurch, Essex.
Richards, D. L.	c/o, City Engineer's Dept., Council House, Coventry.
Salmon, J. W.	2 Grover Avenue, Westdale Lane, Mapperley, Nottingham.
Santos, D. dos.	Z.A.H. Lourenco Marques, A.O.P., Mocambique, Africa.
Skuse, F. N.	"Myrtle Villa," Usk, Monmouthshire.
Smith, B. G.	28 The Crescent, Whitley Bay, Northumberland.
Smith, G. A.	"Rivelin," 12 Woodstock Road, Carshalton, Surrey.
Smith, R. W.	19 Kingsnorth Road, Flixton, Manchester.
Speight, J.	95 Southmere Drive, Gt. Horton, Bradford.
Stokell, R.	The G.E.C. Ltd., c/o, North Borneo Trading Co., Jesselton, B.N.B.
Symons, E. C.	36 Swanside Avenue, Liverpool, 14.
Taylor, C. R.	c/o, The North Eastern Electricity Board, 18 King's Road, Harrogate.
Thakur, L. M.	1 Queen's Gardens, London W.2.
Thorogood, P. A.	35 Gibbs Green, Edgware, Middlesex.
Waingard, S. J.	12 Bellott Street, Cheetham, Manchester, 8.
Wallwork, R.	36 Queen Street, Newton Heath, Manchester.
Wearren, M. G.	Conismere, Horns Road, Stroud, Glos.
Webb, B. R.	The Strand Electric & Engineering Co. Ltd., 29 King Street, London, W.C.2.
Whitworth, Dr. A. B.	65 Lawrence Road, Rugby.
Wilkinson, S. D.	82 Liverpool Road, Birkdale, Lancs.
Wilmut, N. G.	36 Rudthorpe Road, Bristol, 7.
Wilson, R. E.	Northbrook Cottage, Harrogate Road, Rawdon, Nr. Leeds.
Wright, T.	The Auld Hoose, Crofthead, Fauldhouse, West Lothian.
Yardley, L. A.	Aythorpe Roding, Dunmow, Essex.
Zakaria, S.	Dept. of Buildings & Grounds, American University of Beirut, Lebanon.

Student Members

Buller, D. L.	80 Camberley Road, Nover's Park, Bristol, 4.
Burgess, M. A.	33 Eastbourne Road, South Tottenham, London, N.15.
Doel, A. W.	18 Dean Head, Summit, Littleborough, Lancs.
Haydon, G.	Lodwell, Godshill, Ventnor, I.O.W.
Lethbridge, E. P.	89 Atlas Street, St. Helens, Lancs.
Oliver, A. C.	18 West Pathway, Harborne, Birmingham, 17.
Robson, N.	11 The Grove, Upminster, Essex.
Rye, J.	17 Forest Avenue, Fishponds, Bristol.
Sereno, V.	404 Bury New Road, Salford, 7.
Spencer, D. L. N.	45 Kenley Road, Merton Park, London, S.W.19.
Taylor, J. L.	"Bangor," Aberdeen Road, Croydon, Surrey.
Wyatt, W.	10 Barretts Grove, Stoke Newington, N.16.

Transfer from Student to Corporate Member

Brooker, D. G.	200 Mount Pleasant Road, Tottenham, London, N.17.
Curtis, D. A.	Clarence Cottage, Tite Hill, Englefield Green, Surrey.
Fern, D. O.	3 The Copse, Folly Lane, Whippingham, I.O.W.
Spalding, A. R. M.	51 Colville Road, Leytonstone, E.11.
Wall, D.	40 Sandy Grove, Liverpool, 13.

Printed in England by
Argus Press Limited, Temple Avenue and Tudor Street, London EC4
and published by
THE ILLUMINATING ENGINEERING SOCIETY
32 Victoria Street, London SW1

Annual Subscription to Non-Members — £2 . 2 . 0
Price per number to Non-Members — 10s 6d